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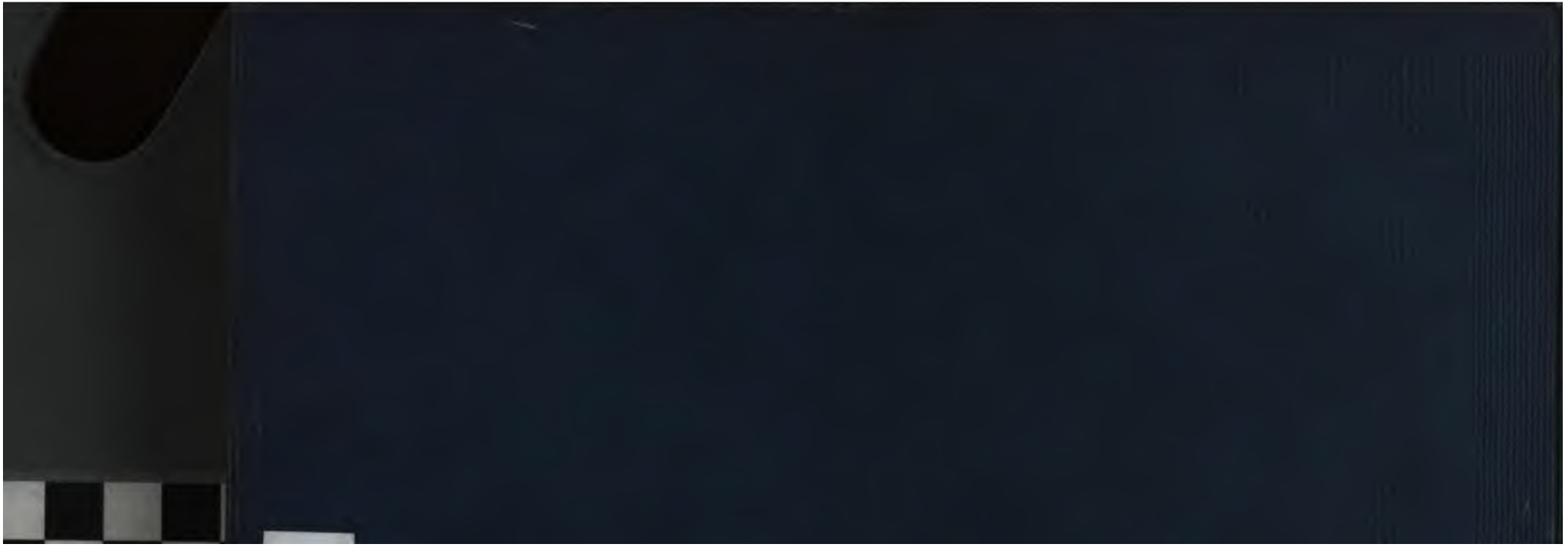

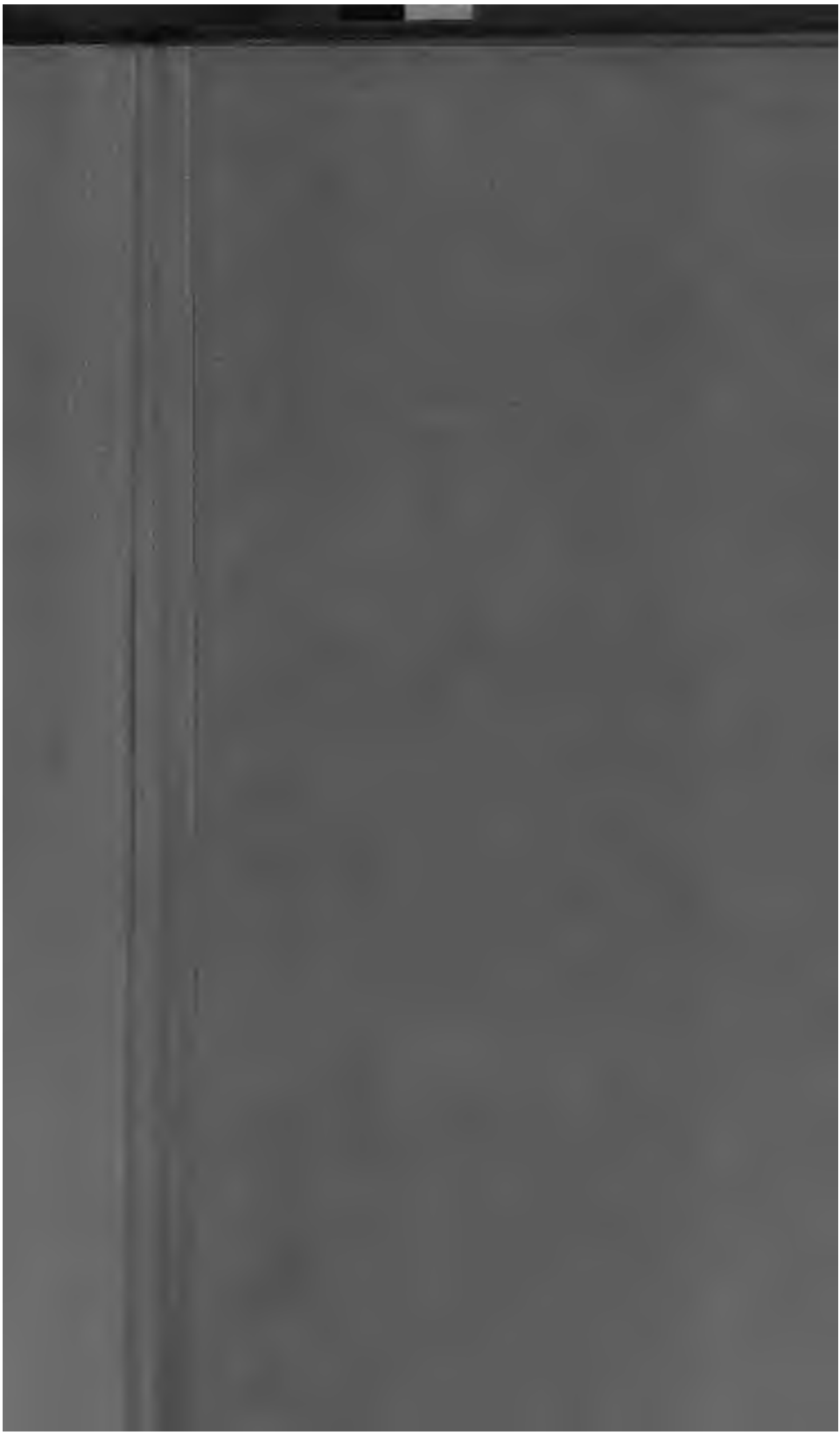

WELDING

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WELDING

THEORY, PRACTICE, APPARATUS AND TESTS

ELECTRIC, THERMIT AND HOT-FLAME PROCESSES

BY

RICHARD N. HART, B. S.

SECOND EDITION
REVISED, ENLARGED AND RESET

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PREFACE TO SECOND EDITION

THE rapid progress of the last three years in both apparatus and methods of welding has made a revision of this book necessary. This is especially true of the arc-welding and oxy-acetylene systems. Arc-welding, which seemed limited in its possibilities a few years ago, has developed to a surprising degree. The keen competition between the different systems, and the endeavor to extend the systems to all kinds of welding, have resulted in striking developments in processes.

The competition seems to have benefited both the welding companies and the metal industry.

I want to acknowledge my indebtedness to Otis Allen Kenyon, without whose help this book would not have been written. The various welding companies represented herein have all assisted in the revision.

R. N. HART.

PEORIA, ILL.,
DECEMBER, 1913

PREFACE TO FIRST EDITION

In spite of the numerous data on the theory, practice, apparatus, and tests of welding contained in the trade journals and metallurgical books, no previous attempt has been made to present this data in sequence under one cover. But in the last fifteen years the subject has begun to be of interest and importance. The electric, thermit, and hot-flame processes are welding all of the metals and are doing *repeat* and *repair* work that has never before been attempted. New brazing methods have also been successfully tried out and the range of good solders greatly increased.

I have given separate chapters to the commercial metals. Few of the metallurgies give much space to the working properties of the metals, especially the welding property, which is often merely mentioned.

Test and cost data must be taken with a grain of salt. The test data have been compiled from various sources. Those tests given for iron are standard and cannot be questioned. Those tests given for the special processes are more recent and in most cases have been made by interested parties. They are no doubt accurate, but at present the special processes cannot be so well represented by test data, as by the actual work they turn out. The same may be said of cost data. The prospective purchaser of welding machinery must figure the cost of his apparatus plus the cost of labor and the depreciation. But above all, he must satisfy himself that the apparatus he chooses is the best for his kind of welding.

I wish to express my thanks for assistance received from the different welding companies mentioned herein; also to James H. DeLong, for special analyses; Dr. Edward Hart, Dr. Joseph W. Richards, Prof. Oliver P. Watts, Otis Allen Kenyon, E. A. Colby, of Baker & Co., and to many others.

R. N. Hart.

Los Angeles, Cal.,
October, 1910.

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DEFINITIONS AND INTRODUCTION

According to the Standard Dictionary, to *weld* is to "unite, as heated metal, in one piece or mass under the hammer or by pressure."

The Century Dictionary says, "To unite or consolidate, as pieces of metal or metallic powder, by hammering or compression, with or without previous softening by heat," * * * "term is more generally used when the junction of the pieces is effected without the actual fusing point of the metal having been reached." While the Standard adds, "Metals are weldable in proportion to the length of time they will stay under heat in a plastic condition without melting."

Welding is distinguished from soldering, which is, according to the Standard, "To unite, as two metallic substances, by solder." The Century, "To unite by a metallic cement," * * * "Every kind must be used at its own melting point, which must be always lower than that of the metals to be united."

I give these definitions because there is some confusion of the terms; and naturally so, as the two processes often are indistinguishable. Thus two unlike metals, as iron and platinum, may be welded; while a fractured steel bar may be united by placing platinum foil between the pieces, pressing strongly together and heating moderately. This is strictly welding, yet the platinum foil is solder. In the recent processes of welding by fusion, the molten metal becomes a solder. Brazing is classed as soldering, but when brass is brazed the process is as nearly welding as the so-called *autogenous* weld.

The word *autogenous* is misapplied to welding. It means *self-produced*. The melted weld of the oxy-hydrogen or acetylene flame is a soldering process in which the metal produces its own solder. However, it makes a catchy trade-name.

Welding, under different names, is a property possessed by many substances, both elemental and compound. According to Roberts-Austen,[1] who devotes considerable space to the *flowing* property of metals, "welding is the property possessed by metals, which on cooling from the molten state pass through a plastic

[1] "Introduction to Metallurgy," p. 47.

stage before becoming perfectly solid, of being joined together the cohesion of the molecules that is induced by the application an extraneous force, such as hammering."

In general, welding occurs if cohesion between the molecules the two pieces can be induced. This cohesion may amount diffusion when the two pieces are of unlike substance, and t metal at the weld will be found to be an alloy of the two. Th gold and lead, pressed together for several weeks, will weld ordinary temperature. At 100 deg. C. they will weld in l time, and the weld will be an alloy of gold and lead.

Welding and diffusion are not inseparable, however. For t welding by diffusion of lead and gold is weaker than the fir named cold weld. While the diffusion of mercury through a other metal invariably produces weakness of that metal, son times disintegration.

Regelation is the name given to the welding of two pieces ice. Faraday is credited with this discovery. He found th two pieces of ice slightly below freezing point, if pressed togeth will weld. Wrightson[1] states that both iron and ice suffer drop in temperature when pressed together. He heated t irons to the plastic state in an electric welder and pressed the together. The recording pyrometer showed a sudden fall from 19 deg. to 57 deg. C. He further states that iron i creased almost 7 per cent. in volume on becoming plastic, a tries to trace an analogy between the behavior of iron and i It has since been found that regelation is a property possess in some degree by most crystalline substances. Pure crystalli salts will regelate under pressure at moderate temperatu Even such a substance as bismuth will regelate.

Evidently welding depends upon two things:

1. *The flow.*

Most of the so-called solids are fluid to some extent. High crystalline, refractory rocks will flow under great pressure. T walls of some deep mines have flowed together in the course time. A rod of glass or of sealing-wax will bend or flow if supports a weight for several days. Lead, sodium, etc., flo readily under pressure.

Flow is almost synonymous with malleability the differen being a matter of time. Many substances which flow slowly w not withstand the shock of the hammer.

[1] *Journal of the Iron and Steel Institute*, 1895, Vol. I, p. 499.

Most metals flow at all temperatures from normal to melting point, but they are the most easily weldable within the range of greatest plasticity. But their welding also depends upon—

2. *The wetting* or cohesion of the two substances.

Two pieces of the same or different substance will not weld if their surfaces do not cohere, no matter how malleable or fluid they may be. Aluminum is a notable instance. The metal is quite malleable at most temperatures, but a microscopic film of oxid prevents the two surfaces from wetting one another. Iron in a lesser degree is troubled with a coating of oxid at welding temperature. Any flux which will clean off both surfaces will allow a weld to be made. In proportion to the ease with which one can have and hold a clean surface of the metals in the range of plasticity, in that proportion welding will be feasible. The welding of malleable metals is dependent on the behavior of the oxids which form on their surface. In proof of this is the remarkable experiment of Chernoff[1] in 1877. He showed that a partial weld of two pieces of iron could be made at the low temperature of 650 deg. C., which is at least 700 deg. below common welding heat. The two surfaces were planed and highly polished. Pressure was applied for several days, when it was found that there was a partial weld. This is similar to the well-known experiment in physics where two plane and highly polished surfaces of glass are pressed together. The surfaces will cohere to some extent.

These two experiments seem to show that whatever assists cohesion, assists the welding. There are numerous instances of welding among non-metallic substances which do not oxidize at the welding heat. Glass is too well-known to need explanation. Pieces of horn can be joined under pressure of hot plates if the horn be kept moist.

Metals newly nascent, in a fine powder, can be welded into a solid piece by a stroke of the hammer. Apparently for the reason that the grains of powder have bright, clean faces. Most of the malleable metals are so weldable.

THEORIES OF WELDING

In 1877, Holley[2] advanced the theory that irons weld in proportion to their mobility or flowing, and inversely as oxidation

[1] *Revue Universalle des Mines*, Vol. I, 1877, p. 411.

[2] *Trans. American Institute of Mining Engineers*, Vol. VI, p. 112.

of the welding surfaces occurs. He thought that the more plastic or the nearer to the melting point the irons were, the more readily they would weld. But with every increase in heat was a corresponding readiness to oxidize—especially on the part of carbon and iron. This oxid interposed a mechanical difficulty to perfect welding.

This theory does not satsify Campbell[1] who insists that impurities tend to crystallization in the body of the iron. Carbon, which is the principal offender, and sulphur, phosphorus, and other ingredients, all form alloys or compounds with the pure ferrite. Ferrite itself is exceedingly malleable and mobile. But a mixture of ferrite and several of the carbon compounds, as cementite, martensite, etc., is stiff above red heat in proportion to the carbon present. Campbell thinks that such a steel, which is really a mineral with granitic structure, will not weld, because it refuses to flow. He claims that oxidation troubles are actually less, because the chemical combination of the iron oxid with the impurities and their oxids would give a self-fluxing surface.

According to Campbell, then, those impurities which caused decided crystallization with accompanying brittleness, interfered with the flow at high heat and prevented welding. Manganese, it is true, makes a more brittle iron, up to 1.20 per cent.; but it prevents crystallization of sulphur, etc., and is an aid in welding.

For ordinary and commercial purposes the welding must be done in a few seconds' time, and the previous cleaning and heating must not take long. This at once limits to a very few the number of metals which can be welded; were it not for the recent remarkable advance due to the electric, oxy-hydrogen and acetylene processes of melting, welding would be confined to iron, platinum, nickel, and gold. Other metals would be joined by soldering and brazing, and even then the metal worker would have great difficulties with aluminum and many alloys.

I will first take up iron and steel welding. As much research work has been done on the metallurgy of iron as on all of the other metals combined. It is extremely probable that many of the difficulties and problems arising from proportions of impurities and methods of producing will apply equally to other metals. For this reason, and because of its overwhelming importance, I will treat of iron more thoroughly.

[1] "Metallurgy of Iron and Steel," p. 589.

WELDING

PART I

THE METALS

Iron

Pure or nearly pure iron is readily weldable at a white heat. Malleable, or nearly pure wrought iron, is known as *weld iron.* The range of temperature in which it can be welded is very wide: it runs from the imperfect weld at cherry-red, to dazzling white, when the welding property is lost before the iron melts. According to Pouillet, the different colors of heated metals are represented approximately by the temperatures given:

	Deg. C.
Incipient red	525
Dark red	700
Incipient cherry	800
Clear cherry-red	1000
White	1300
Dazzling white	1500
Melting	1550

Wrightson[1] states that he found iron to increase in volume as much as 7 per cent. when passing into the plastic stage.

Malleable Iron.—*Weld iron* is a name occasionally used to describe malleable iron, indicating that it is pure enough to be welded. Malleable iron is produced by the puddling process. It is made by melting up pig iron and scrap in an open-hearth furnace and burning out the greater part of the silicon, manganese, and carbon in the order named. As the burning continues the melting point of the iron rises, and it becomes a pasty mass permeated with slag from the stirring. This nearly pure iron is gathered into "puddle balls," and taken to the rolls at a white heat. It is rolled or hammered out into long strips, the strips

[1] *Journal of the Iron and Steel Institute,* 1895, Vol. I, p. 463.

are cut, reheated to white heat, and welded together between the rolls or beneath the hammer. To produce the finest wrought iron, the process of rolling and welding is repeated. This is the puddling process in brief; its object is to squeeze and work the slag out of the iron and to give the iron a fibrous structure like rolled copper.

The principal chemical difference between wrought iron and steel is the carbon content. In fact, except for its high carbon, basic open-hearth steel is purer than most malleable irons.

All weldable iron is not malleable, but it is weldable in proportion to its malleability. As is seen in the foregoing process, the iron is welded several times.

How to Weld Iron.—The mechanics of a "smithed" weld is in the main as follows: Suppose the smith wishes to join two short bars of malleable iron, of cross-section 1 by 2 inches. He first hammers or cuts a convex bevel or "scarf" on the ends of each bar, as shown in Fig. 1.

FIG. 1.—Views of scarfed bars for lap welding.

The heating must be done in a coke or coal forge. Coke is the best fuel for the reason that it gives a good reducing flame. The fire is blown with the bellows until it is at a high heat. The ends of the bars are thrust well into the midst of the ignited coke and more coke is piled over them. The blowing is continued until the bars are red-hot on the ends, when the smith takes them out with pliers and dips them into pure sand or borax near by. This is the flux, and it so acts on the surface of the iron as to clean it of rust and forms a glass that protects the fresh iron from further rust. The smith puts his irons back into the forge again and heats them until white.

When white, or nearly white-hot, the smith takes one bar in his pliers, his helper takes the other, and they place them together on the anvil, the one lapping the other (Fig. 2). Both the smith and his helper give the pieces quick, light blows with their hammers until the plastic iron is well-joined. They turn the irons while hammering to get an even weld on all sides.

The smith will try to weld at a white, but not a dazzling white,

heat, and he will try to complete it without putting it back into the fire for a reheating.

When the weld is finished, he may give it a special shape by placing it between swage blocks and hammering.

This simple operation of welding requires much skill, as will appear. The smith may find that with all his skill his joint is bad or that his iron will not join at all.

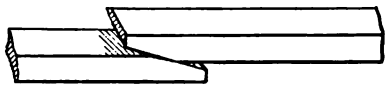


FIG. 2.—Bars in position for lap welding.

Points in Practice.—In practice there are the usual number of details requiring skill that the smith must observe.

The contact faces should always be shaped so that their middle points touch first and so that hammering causes union first at the middle. This prevents slag becoming enclosed.

The heating should be done rather slowly, so that the pieces will be of uniform heat at the weld. Both irons should be of the same temperature. To effect this the smith must not blow up his fire too hot and must watch the color of both irons. A deep bed of coals will give a flame the least oxidizing, because most of the oxygen will burn to carbon monoxid or dioxid.

The welding heat is quite different for different irons. The smith must use his judgment, taking good care he does not overheat his irons. Overheated iron, miscalled "burnt iron," will be brittle on cooling. Steel is much more sensitive to overheating than iron. It is seldom safe to heat steel above redness.

The iron should be well fluxed directly on the contact surfaces, and not merely around them, as is too often the case. The common fluxes for iron are pure silica (river sand) and borax. Impure malleable irons are self-fluxing to a certain degree, but this cannot be relied on. Other fluxes are calcined borax and sal ammoniac. One writer[1] recommends powdered marble, which is limestone, the flux of the blast furnace. Borax is recommended for steel on steel or steel on iron, as silica is inadequate.[2] Besides fluxing the bars before raising them to welding heat, the smith may sprinkle calcined borax on the irons when they are ready to

[1] "The Blacksmith's Guide," J. S. Sallows.

[2] "Testing of Materials of Construction," W. C. Unwin, 1899, p. 292.

weld, to replace it on surfaces accidentally rubbed bare in the forge.

The hammering, or "working," is very important, and must be done rapidly. The smith manipulates his bars so that welding begins at a middle point and works outward, driving the slag away from it. The first few blows of the hammer should not be heavy. If the pieces are large or the smith slow, his heat will fall before the weld is finished and he must put his bars back in the fire. Second heating must be avoided if possible; slag is apt to get in the weld or the pieces may become "burnt," to say nothing of the time lost.

The different kinds of welds known to the smith—butt, lap, scarf, jump, cleft—are variations of simple welds. Illustrations of them and of how the stock should be shaped are given in Figs. 3 to 7. The method of hammering will suggest itself in each case. Jump and butt welds will have sufficient upset to work on, while

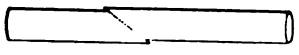


FIG. 3.—Lap weld. No upset.

FIG. 4.— Lap weld. Upset.

scarf welds, will not unless the pieces are jumped or over-lapped considerably.

Welding Fires, etc.—The ordinary fire used by the smith for his welding is a deep bed of coke. But the fire may be fed with hard or soft coal; it may also be a gas or oil flame.

For blacksmithing, the coke fire is much the best. In this fire nearly pure carbon is burned, and the resultant gases are carbon monoxid and dioxid. The carbon monoxid and the coke are reducing in their action. They will prevent the metal heated from oxidizing and will even clean the metal of scale.

Hard coal can be used, but in a small forge it is impossible to get a hot enough fire. Soft coal is a poor coal for forge work. It has, as a rule, high sulphur, which the hot iron readily absorbs to its detriment. While the thick carbon smoke of the flame is apt to collect on the iron in an oily soot unless the flame can be kept hot enough.

Gas and oil flames are often used for chain welding and similar operations. The gas or oil should be fairly free from sulphur. The gas flame is made by injecting the gas through a large Bunsen burner. Air is introduced through the holes in the burner

a short distance from the burner end. Or if the gas is under sufficient pressure to make a roaring flame, it will take in enough air at the end of the burner. The proper mixture gives a nearly colorless flame. The quickest and best way to tell if a flame is right for welding is to heat in it a small piece of steel or soft iron. If the flame has too much air, the metal piece will rust and scale off in the flame. If too little air, the soot will collect on the metal and it will not heat quickly. Gas flame is the most convenient for most purposes. It is easy to regulate and can be

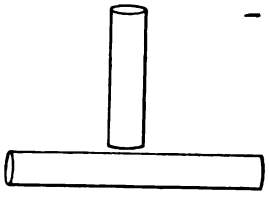


FIG. 5.—Jump weld.

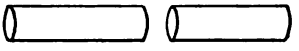


FIG. 6.—Butt weld.

turned on the iron while welding. In this way iron can be welded without flux. When chain is made the links are hung on a bar above a long narrow furnace of fire bricks. The flame is played beneath.

The oil flame is a cheaper flame than gas. It can be manipulated in the same was as a gas flame. But the oil must be free from sulphur compounds to make a safe flame.

It has lately been tried to burn gases that have been preheated.

FIG. 7.—Cleft weld.

If coal gas, starting to burn at 35 deg. C., will give a combustion point of about 2000 deg., then by preheating it to about 800 deg. C. and burning, there will be a gain of 400 or 500 deg. in the temperature of the flame. In other words, the welder has boosted his flame up to about 2500 deg., a very respectable temperature.

The preheating is done by passing the gases through copper coils which are nested above the welding-flame flue, and which receive the heat from the welding flue.

Causes of Poor Welds.—Suppose we have an iron or steel that will weld. There are still many good reasons for discrediting the safety of the joint until it has been tested. They are:

1. *Imperfect Contact.*

a. The two surfaces may give the appearance of perfect union, but a considerable percentage of the central portion may be faulty. For if the metal in course of puddling is not relieved of its enclosed slag, this will be finally pressed out into thin laminæ. These cleaving planes will be parallel with the bar until it is welded, when they will be upset in all directions at the joint. A network of such planes now running across the bar instead of parallel to it will greatly diminish the tensile strength.

b. Then, again, the smith may carelessly allow some of his flux to stay within the weld. All the hammering in the world will not remedy it. In most cases one of the pieces can be

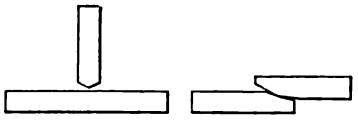


FIG. 8.—Correct shapes for jump and lap welds.

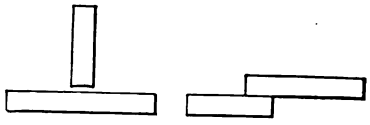


FIG. 9.—Incorrect shapes for jump and lap welds.

scarfed or pointed, so that the first contact of the hot pieces will be at a central point. As the hammering proceeds, the slag will be forced out of the joint as fast as the pieces weld (see Fig. 2). This caution applies equally to the smithed weld or the Lafitte joint (see page 185).

c. Or the smith may not flux his bars correctly, thereby allowing unreduced and uncombined oxid of iron to get in the weld. It is not a difficult thing to get this rust incorporated in the weld, because it is soluble in iron. Dissolved rust makes a "burnt" or brittle joint. Clean silica sand is the common flux. The smith dips his hot bars into a box of the sand kept near by, and often sprinkles a handful over the pieces when hammering if the pieces are large. The reaction between the sand and the rust is rapid. Iron silicates, easily fusible, are formed. They cover the fresh iron surface with a thin glass, which prevents further oxidation.

2. *Insufficient hammering or "working"* may account for the poor weld. The iron may be perfectly joined, yet the structure

is weak and uncertain. Wrought iron has a fibrous structure similar to wood. The smith must do his best to continue this structure through the weld. With a lap weld he can start with a heavy upset which can be hammered down. Hammering serves the double purpose of consolidating the metal and of laying the cleavage planes perpendicular to the blows. Much hammering is impossible with jump and butt welds. The lapwelding of wrought-iron pipe and the scarf-welding of chain links must depend on pressure for their perfect finishing. Welds of steel cannot often be much benefited by working. Steel is an alloy, without structure. To be strong it must be solid and homogeneous. Campbell's advice is to keep the critical temperature high and keep down the silicon and phosphorus when choosing your steel.

3. *Too high a heat* is responsible for some bad welds. Very great heat will unsettle the structure of the iron in the stock a considerable distance from the joint. Because the bar breaks near, but not on, the joint, is no proof of the soundness of the weld. The structure of the iron is impaired wherever the heat is beyond the critical point of crystallization of any important impurity. By this is meant that if there be an appreciable amount of carbon, for example, it will tend to mineralize the iron when the latter is cooled down past the crystallization point of the first carbon-iron mineral. A number of other impurities, silicon, aluminum, arsenic, etc., are presumed to act in like manner. So the smith must work his weld and also all of the surrounding metal that has been raised above this critical temperature. Just what is the critical temperature is unknown to him, because it varies with every iron, according to the amount and proportion of its impurities.

Oftentimes welds are made which cannot be worked to advantage. Such welds are apt to be weak. The only present remedy is to select for such purpose iron as free as possible from objectionable impurities. Machine welds, such as small chain links and small-bore pipe, where the entire piece must be heated, are especially subject to this disadvantage.

4. *Large welds are unsafe.*

Just what is the maximum cross-section of practicable welding cannot be safely laid down. Welding is not advisable where it is difficult to get a good welding heat, to flux properly, to joint the pieces well and accurately, or to work the weld when made. To

weld a ship's sternpost or skeg or rudder-post was a matter of weeks of expensive and often hopeless labor before the advent of thermit (see page 148). To weld a large driving-rod, an embossing die, crushing roll, or propeller shaft was impossible. The largest iron pipe used, however, could be welded; also chain links a foot or more long, and 2- or 3-inch stock could be safely welded.

Campbell says,[1] "Welds of large rods of forging steel are entirely unreliable. Incandescent electric methods do not offer a solution of the problem, for during the process the metal is heated far beyond the critical temperature." Thermit, since discovered, does offer a partial solution, because a thermit weld can be reinforced with as much metal as needed, and the metal itself can be varied to meet the requirements. Its cost is to be considered. The oxy-acetylene melt-weld and the electric arc should recommend themselves for like reasons.

Effect of Impurities, etc.—In order to make a good weld of iron, the metal must possess plasticity, which is directly affected by the contained impurities. The welding temperature seems to be the point at which the iron becomes semiplastic, but is still not sufficiently hot to burn or oxidize rapidly. For the reason that this temperature varies considerably for the different alloys of iron, it is impracticable to make any definite rules. A number of impurities or alloy formers affect the welding property to a marked degree even when present in fractional parts of 1 per cent. Substances which cause "red shortness," such as sulphur, or which oxidize to form an impervious skin, such as aluminum, must be avoided in iron.

In the case of cast iron, which is iron high in carbon and silicon, the metal passes suddenly from a crystalline to a liquid condition. It cannot, therefore, be welded over the smith's forge, and can be welded only by one of the recent special processes.

There are an infinite number of kinds of iron, due to the proportions of the combined impurities and the method of treatment during the milling. Each of these so-called alloys will act differently at the welding temperature, while many of them cannot be welded by the smith at any temperature. There are a few general rules which will help the worker in the selection of his material. But there is so much room for failure in welding the

[1] "Metallurgy of Iron and Steel" p. 588.

best irons that what cannot be blamed on the smith and his material must be laid to the devil.

Carbon in the combined state should be kept below 0.30 per cent., because it is a hardener and makes brittle in the combined state. Carbon has been found to amalgamate with iron to form a number of alloys, which are unworkable in proportion to their carbon content. W. C. Unwin[1] gives 0.90 carbon as the limit for welding iron with silica flux; 1.10 carbon as the limit with any flux. These alloys,[2] pearile, martensite, cementite, etc., mineralize in the iron and form a granitic structure on cooling. It is likely that all of the mineral impurities of iron behave in this manner.

In the uncombined form, as graphite, carbon does not affect the welding property, except that it becomes an enemy to the homogeneous structure of the metal, just as does slag.

Slow cooling, drawing the temper, keeps the combined carbon at a minimum. Silicon in a quantity approximately over 1 per cent. and aluminum even more potently, also reduce combined carbon to graphite. However, the objection to silicon is that it makes a brittle alloy, and aluminum oxidizes to the disadvantage of the metal. Slow cooling is valueless for the reason that welding is done at a high heat, when iron is capable of absorbing carbon in greater quantity.

Hence high carbon in the stock cannot be toned down and should be avoided. It should never be above 0.50, and ought to be below 0.25 for the best results.

Silicon causes brittleness, which does not yield to welding heat. It must be kept below 0.20 per cent. Silicon is the element which differentiates cast iron from mild irons and steel. An iron with gray-colored fracture contains too much silicon to use in welding.

TABLE 1.—WELDING PROPERTY OF SILICON STEELS[3]

The weld	Si	C	P	S	Mn
Unsatisfactory..	0.21–5.08	0.14–0.26	0.08	0.05	0.14–0.29
Perfect.....	0.01–0.504	0.16–0.18	0.051–0.121	0.028–0.094	0.455–0.622

[1] "Testing of Materials of Construction," W. C. Unwin.

[2] Wm. Campell, *Electrochemical and Metallurgical Industry*, Feb., 1904.

[3] Campell, "Metallurgy of Iron and Steel."

It will be noted that the second series of steels gave perfect welds with a content of 0.504 silicon, by above analysis; probably accounted for by the high manganese, which will prevent crystallization.

Phosphorus makes the "rotten iron" for thin and sharp castings when present in quantity approximately over 0.10 per cent. Malleable iron for welds should contain less than 0.03 per cent. of it, not so much to assist welding, as to insure a strong joint on cooling.

Sulphur is one of the deadly enemies of the smith. Its effect on iron is especially disastrous at welding temperature, even when not otherwise apparent. In quantity approximating over 0.10, it causes "red shortness," brittleness. It should be kept as low as possible. Manganese is the remedy for sulphur, used in the production of iron, but the smith cannot correct it with manganese himself. Very low sulphur content is the secret of the success of Swedish iron in the arts.

Manganese may be present up to about 1.50 per cent. in iron or steel to be welded. Up to this limit its effect is generally beneficial. Campbell states that between 2 and 6 per cent. it forms a brittle unworkable alloy. Hadfeld's steel, with about 7 per cent. manganese, again becomes malleable.

Manganese is the cheapest tonic of the iron producer. It reduces both sulphur and oxygen in the iron and rises to the top as slag. The remainder, if any, forms a tough workable alloy with the iron.

Nickel steel welds readily at all compositions. Nickel is a valuable addition to iron, because small percentages of it greatly increase the tensile strength without impairing the elasticity. It is also valuable because it prevents rust in its iron alloys to a marked degree. Nickel steels of from 2.05 to 4.95 per cent. nickel are specifically mentioned as weldable if the carbon is kept down.[1]

Chrome steel[2] can be welded. The first hammering must be very gentle so that the metal will not fly to pieces.

Aluminum.—There is some uncertainty about the effect of small quantities in iron. In amounts above 3 per cent. it forms a valuable alloy with steel, which is highly fluid on melting. 0.50 per cent. increases the tensile strength and elastic limits

[1] *Iron Age*, July 25, 1905.

[2] R. Brown, *Journal of the Iron and Steel Institute*, 1896, Vol. I, p. 472.

from 3000 to 8000 pounds and lessens the ductility.[1] Odelstjerna[2] says that only 0.002 aluminum gives inferior steel castings, the fracture being coarsely crystalline.

A serious count against aluminum, if it be true, is that it oxidizes in its alloys and coats them with a skin. This would seriously affect the welding, because this skin is a very refractory, unmanagable substance. Reliable data are wanting.

Copper is generally believed to be harmful in malleable iron. However Campbell[3] in his welding experiments used bars containing 0.35 per cent. with excellent results. He says: "The critical temperature at which the steel ceases to be malleable and weldable varies with every steel. It is lower with each associated increment of copper; it is higher with each unit of manganese, and it is lower in steel that has been cast too hot."

Arsenic steel, with less than 0.20 per cent. arsenic will weld as usual. Between 0.20 and 1.20 per cent. a flux of borax and sal ammoniac is needed. 2.75 per cent. arsenic prevents welding altogether, and the iron behaves like pig iron.[4] Campbell[5] claims that so small an amount as 0.093 impairs the welding property. He says that 0.20 per cent. of arsenic increases the strength and reduces toughness.

Nitrogen content is not a subject for the smith to bother about. Nitrogen has been blamed recently for otherwise unaccountable failures of chemically good iron. E. J. Sjöstedt[6] claims that infinitesimal quantities of it cause red and yellow shortness. He claims that a furnace producing trisilicate slag gave iron with 0.003 per cent. nitrogen; bisilicate slag, 0.016 per cent. nitrogen; monosilicate slag 0.024 per cent. nitrogen. 0.006 per cent., he says, is the limit for good steel and, presumably, for good welding steel.

However, there is at present no easy way of recognizing its presence, and it cannot be guarded against.

Tests of Smith Welds.—Campbell made a series of tests of smithed welds of all of the different kinds of steel and of wrought iron, the results of which are given in tabulated form in his

[1] "Metallurgy of Iron and Steel," Wm. Campbell, p. 477.
[2] *Transactions American Institute Mining Engineers*, Vol. XXIV, p. 312.
[3] "Metallurgy of Iron and Steel," p. 467.
[4] *Iron Age*, April 13, 1899.
[5] "Metallurgy of Iron and Steel," p. 478.
[6] *Iron Age*, May 5, 1904.

"Metallurgy of Iron and Steel." Four smiths of ability and experience welded the metal in flats and rounds of size and shape most convenient for handling. And though the men knew their bars would be tested, their welds were often far from satisfactory. "Picking out the worst individual weld of each workman, blacksmith 'A' obtained only 70 per cent. of the value of the original bar, 'B' 54 per cent., 'C' 58 per cent., and 'D' only 44 per cent. The forging steel showed one weld with only 48 per cent., the common soft steel 44 per cent., while even the pure basic steel gave one test as low as 59 per cent."

But the tensile strengths of the bars are fairly uniform when compared with the elongation. "In some cases where the break took place away from the weld, the elongation was nearly up to the standard." The elongation test of a basic open-hearth steel of low carbon gave greater elongation in welded pieces than in the natural bar; "but in the other pieces the stretch was low and the fracture so silvery that it was plain the structure of the bar had been ruined. In most cases where the test bar broke in the weld, the pieces parted at the surfaces of contact, showing that no true union had taken place; one or two fractures were homogeneous, but they showed the coarse crystallization that follows overheating.[1]"

TABLE 2.—WELDING TESTS OF THE ROYAL PRUSSIAN TESTING INSTITUTE[2]

Kind of metal	Ultimate strength, lb. per sq. in.		Per cent. elongation in 200 mm. = 7.87"		Per cent. of reduction of area	
	Average of 6 tests natural	Average of 9 tests welded	Average of 6 tests natural	Average of 9 tests welded	Average of 6 tests natural	Average of 9 tests welded
Medium O. H. steel...	72110	41820	20.8	3.2	31.9	4.5
Soft O. H. steel.....	64570	45800	25.1	5.1	44.7	10.5
Puddled iron.....	57890	47080	22.2	7.7	39.5	14.0

These results agree substantially with those of Campbell. The lowest result for soft steel was 33 per cent., the average 71. The lowest result for medium steel was 23 per cent., the average 58.

[1] "Metallurgy of Iron and Steel," Wm. Campbell.

[2] *Journal of the Iron and Steel Institute*, Vol. I, 1883, p. 425.

The lowest result for puddled iron was 62 per cent., the average 81.

These results confirm the general impression that puddled iron is the best iron for welding. Contrary to one authority who says that iron before puddling welds more easily because of the presence of the slag in the iron.

The *welding test*[1] is occasionally specified in this country on account of the common use of welds in structural work. Two iron bars of the metal under test, of about 1 inch section, are scarfed, heated to white heat, and joined without flux. The joint is worked with an 8- or 10-pound hammer, and brought down to unit section. It is cooled without chilling. This bar is then tested for tensile and elastic strength; and a similar weld is half cut open, bent until fractured, and examined for structure.

TABLE 3.—RESULTS OF TESTS BY PROF. BAUSCHINGER

Kind	Section, sq. in.	Ratio of strength at weld to strength of bar, per cent.
Soft steel and ingot iron.....	0.15 to 2.00	89, mean, 57 to 105, range
Wrought iron.....	0.15 to 2.00	95, mean, 83 to 102, range

Welds made with steam hammer were 10 per cent. stronger for mild steel and 5 per cent. stronger for wrought iron on the average than hand welds.

TABLE 4.—RESULTS OF TESTS BY W. C. UNWIN[2]

Percentage of carbon	Ratio of strength at weld to strength of bar, per cent.	
	Series A	Series B
0.75	59	68
1.00	76	51
1.00	50	84
1.15	89	113
1.15	75	117
1.25	75	86

[1] *Transactions of the American Institute Mining Engineers*, Vol. II, p. 628.
[2] "Testing of Materials of Construction," 1899.

TABLE 5.—RESULTS OF TESTS BY DAVID KIRKALDY & SON[1]

Kind	No. of tests	Size of test bar, inches	Ratio of strength at weld to strength of bar, per cent.	
			Mean	Range
Electric weld	17	1.129 diam.	89.1	
Smith weld	19	1.116 diam.	89.3	
Steel bolts, welded	28	¾ to 2½ diam.	75.1	71.5 to 88.8
Iron bolts, welded	181	¾ to 2½ diam.	73.8	61.7 to 88.2
Iron tie-bars, welded	18	1¼ to 3.13 diam.	59	37 to 74.2
Iron tie-bars, welded	10	2.5×(.24 to 68)	76.7	
Iron plates, welded	7	10×.87 to 6×1.11	65.5	57.7 to 83.9
Iron chain links	1086	$\frac{1}{16}$ to 2 (area turned)	86.4	72.1 to 95.4
Bar plate, welded	14	¾ to 1¼ thickness	68.8	52.6 to 82.1

Conclusions.—Holley[2] gives three conclusions concerning iron:

"1. None of the ingredients except carbon in the proportions present seems very notably to affect the welding by ordinary methods.

"2. The welding power by ordinary methods is varied as much by the amount of reduction in rolling as by the ordinary differences in composition.

"3. The ordinary practice of welding is capable of radical improvement, the most promising field being in the direction of welding in a non-oxidizing atmosphere."

He gives his maximums for the impurities as follows: P, 0.317; S, 0.015; Si, 0.321; Mn, 0.097; Cu, 0.45; Ni, 0.34; Co, 0.11; slag, 2.262.

Campbell's deductions are:

"1. With the exception of manganese in small proportion, the usual impurities in steel reduce its welding power by lowering the critical temperature at which it becomes coarsely crystalline.

"2. A small content of manganese aids welding by preventing crystallization.

"3. Only the purest and softest steels can be welded with any reasonable assurance of success.

[1] "Strength and Properties of Materials," W. G. Kirkaldy, 1891.

[2] "The Strength of Wrought Iron as Affected by its Composition and its Reduction in Rolling." *Transactions American Institute Mining Engineers*, Vol. VI, p. 101.

"4. The confidence of a smith in his own powers and his belief in the perfection of the weld is no guarantee that the bar is fit to use."

According to Kent:[1] "No welding should be allowed on any steel that enters into structures."

PLATINUM

Though a rare metal, being at this writing more expensive than gold, platinum is much used for analytical apparatus. Between the years 1827–44 it was used by the Russian government for coinage.[2] But it is now largely made into tubes, wire, crucibles, receptables, etc., to be subjected to high temperature and to come in contact with various acids and alkalies necessary for rock analysis; also for leading-in wires for incandescent lamps and for sparking points for electrical apparatus.

Platinum melts at 1760 deg. Cent., is seventh in the malleability scale and first in ductility (Prechtl). Heated in presence of oxygen, it begins to lose weight at 800 deg. Cent. It absorbs hydrogen when heated and gives it off again on cooling, and its surface becomes rough.[3] Like iron, it is highly weldable; best at white heat, though also at a dull red. It does not oxidize in the air, hence needs no flux, though the surfaces should be polished.

The need for welding platinum sometimes arises, as in the case of analysis tubes made of sheet platinum, the joining of tubes, wires, etc., and the fabrication of apparatus and the insertion of patches in burnt-out crucibles.

Before a flame intense enough to melt the metal had been discovered, the platinum refiner took advantage of the welding property in making his ingot. Sponge platinum, resulting from the last stage of refining, was heated to redness. It was then pressed strongly together to form a cake. The cake was heated to white heat and hammered to a compact ingot.[4]

The oxy-hydrogen blast was applied to the heating process about 1847 by Dr. Hare, of Philadelphia; and later the hammering was dispensed with and the platinum was simply melted into an ingot.

Platinum was originally soldered with gold or with difficulty

[1] "Mechanical Engineer's Pocket Book."
[2] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. II, p. 1350.
[3] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. II, p. 1350.
[4] Encyclopædia Britannica, Vol. XIX.

welded. The oxy-hydrogen flame makes the process much easier, as the metal readily melts under this heat. On account of its tendency to absord hydrogen and consequent bubbling of the surface, it is necessary to keep a slight excess of oxygen in the flame.

The oxy-acetylene flame would also answer the purpose, though it would be necessary to keep a considerable excess of oxygen in the flame. Carbon from the acetylene would rapidly attack the platinum.

I am indebted to Mr. E. A. Colby, of Baker & Co., platinum refiners, for the subjoined special information, which covers points hitherto untouched in the literature of platinum and its allied metals.

"The oxy-acetylene flame can undoubtedly be used for the welding of platinum, but is not by ourselves for the reason that the temperature available is far in excess of that necessary, and lack of experience leaves us in doubt as to the effect of the by-products upon the metal from the acetylene flame. We consider the oxy-hydrogen flame far safer and, as the heat is not so concentrated, it is more useful where large surfaces are to be treated. Care, however, must be exercised to have the component gases (hydrogen and oxygen) present in approximately the necessary amounts for perfect combustion. Platinum takes up hydrogen at high temperatures and becomes more or less brittle, depending upon the amount of hydrogen retained.

"No flux is required in the welding of platinum or of other metals of the same group, osmium excepted.

"For the same section, the strength of the weld is undoubtedly weaker than that of the body of the metal. Just how much weaker we cannot state from observation, but, as a welded joint is not submitted to the same mechanical working as the body of the metal, its strength is not to be considered as equivalent. In practice, however, the welded portion is slightly increased in section over the body of the metal, and under these conditions there is no material difference in the strength.

"Iridium, osmium, and other metals of the platinum group, when present in small quantities, do not apparently increase the difficulty of effecting a joint, but the strength of the joint is considerably less, as alloys of platinum and members of that group become more and more brittle with increase of the foreign substances. No difficulty, however, is experienced in welding iridio-platinum containing as high as 30 per cent. iridium. Additions of even minute quantities of osmium to an alloy of this composition, however, make it extremely difficult to obtain satisfactory results.

"Platinum can be united to various other metals, such as copper,

nickel, etc., but it is an open question as to whether the union can be considered as a true welding. Undoubtedly, an alloy is formed of the two metal at the surface of contact possessing sufficient mechanical strength for the purposes for which such welds are used. The only illustration of welds of this character are to be seen in the construction of the ordinary incandescent lamp, in which the copper wires attached to the filaments are joined to the platinum wires sealed in the glass by fusing a piece of copper on to the end of the platinum wire. This operation is conducted in automatic machines, and has proven very satisfactory for the purpose."

GOLD

Gold is the most easily weldable of all the metals. Like lead, it can be welded cold and, provided it is free from certain impurities, it can be joined at all temperatures. Gold is generally placed first in tables of malleability and ductility. These properties are destroyed by certain impurities, notably antimony, arsenic, and bismuth. One part of bismuth is 1920 parts gold is alone sufficient to interfere with the working properties of gold.

Pure gold melts at 1062 deg. Cent. and will not oxidize at any temperature. Hence the surface will be clean and weldable. The welding property is very apparent with gold leaf, which must not be allowed to fold on itself lest the surfaces stick together. Gold fillings in dentistry are made by the cold welding of gold leaf.

Pure gold is soft and is seldom used in the arts. To render it strong and durable for coinage and jewelry, it is alloyed with copper and sometimes with silver. Thus the gold coins of Great Britain contain eleven parts gold and one part copper. Those of France and the United States nine parts gold and one part copper. For jewelry both copper and silver are used, the purity of an alloy being designated by the number of *carats* of gold in a total of 24 carats.

The gold of coinage and jewelry cannot be joined without a flux. The flux may be boracic acid or a solution of zinc chlorid and water. In the making and repairing of gold jewelry a mouth blowpipe is used for small and delicate work, and for larger pieces a gas blowpipe with a foot-pump air-blast or compressed air. The flux mentioned is used in case the surfaces oxidize when heated. If the gold is so alloyed as to be hard up to the melting point, the weld will be a melt-weld. Low-carat alloys melt

considerably lower than pure gold. Hence the melt-weld would be made at about the temperature that high-carat alloys would be plastic enough to weld.

Gold can also be readily welded by electricity.

For ordinary cheap and quick joining in jewelry, gold is soldered with soft solder, a mixture of two parts tin and one part lead. The flux is a solution of zinc chlorid in water. Such a joint is condemned by the best jeweling practice: the joint is not strong; it is a different color than the gold; the solder is apt to destroy the strength of the gold at the joint.

The following table of hard solders, given by Gee[1], are yellow alloys of high melting point and make strong solders:

TABLE 6.—COMPOSITION OF HARD SOLDERS

Kind	Fine gold	Fine silver	Copper
Best solder.....	12½	4½	3
Medium solder..	10	6	4
Common solder.	8½	6½	5

These alloys are rolled into ribbons and cut up into "pallions," or may be applied in dust by filing. A description of the soldering of gold would properly belong to a treatise on the goldsmith's art.

SILVER

Silver is also a metal of history. The ancient Greeks knew of it as the metal *electrum*, an alloy of gold and silver, of a brilliant pink-whiteness. Silver is now used largely as a silver-gold or silver-copper alloy, in which the gold or copper is present in approximately 10 per cent. Only rarely is the pure metal used, as for filigree work or for alkali retainers.

Pure silver melts at 960 deg. Cent., and is commonly placed second in tabes of ductility and malleability. It does not oxidize in air when heated. All of these qualities point to the supposition that it is readily weldable. But though pure silver is made into filigree work, it is always soldered. The common alloy for jewelry being a combination with copper would suggest

[1] "The Goldsmith's Handbook," G. E. Gee, p. 136.

at once that soldering or brazing is necessary. In recent years, however, silver has been successfully joined in the electric welder, both to itself and to other metals. Because of its high heat and electric conductance it requires more current, as is also the case with copper.

The joining of silver to silver is effected in jewelry shops with a mouth or gas-air blowpipe and with fine silver as a solder. Other solders are alloys of silver and copper; silver, copper, and zinc; and silver, copper, zinc, and tin. These alloys are given in order of their melting points, the most refractory first. The flux is borax.

It would be well to bear in mind that tin is even more harmful to the working properties of silver than it is to gold and aluminum. Even fumes of tin will alloy with silver and make it brittle. For this reason tin should not be used in solder.

ALUMINUM

Aluminum is one of the youngest of the metals. It was discovered by Wœhler in 1827. At first its considerable expense prevented its being generally used. About 1889, however, the discovery of new processes for its reduction from bauxite, etc., cheapened aluminum, so that it has become a commercial metal. Since then the expiration of the patents covering many of the reduction processes has brought the price still lower.

Fairly pure aluminum is plastic at ordinary temperature, being sixth in ductility and second in malleability.[1] It melts at 655 deg. Cent.; its plasticity increases with heat up to about 600 deg. Cent., when it becomes hot short, and will crumble under the hammer. It is easiest to work between 350 and 400 deg. Cent. Its tensile strength runs from about 14,000 pounds per square inch for cast bars up to 50,000 pounds per square inch for rolled metal and wire.

It was at first thought that its lightness (sp. gr. 2.6) was its most valuable property. But the experimenters soon found that it formed valuable alloys. The aluminum bronzes, aluminum-iron (about 7 per cent.), and some of the three- and four-metal aluminum alloys were found to be good metals for castings for bearings, and in many instances will eventually displace brass, bronze, and even steel.

[1] Aluminum Company of America.

Aluminum has two natural disadvantages. It is electropositive and it is difficult to weld or solder. As late as 1903, one of the prominent periodicals[1] said editorially: "Undoubtedly the man who discovers a good aluminum solder will make his fortune, for it is the want of this accessory that seriously hinders the development of aluminum manufacturers."

Pure alumimum does not oxidize at ordinary temperature, but when heated becomes coated with a thin film. This film is presumably oxid, though it is so thin that not enough of it can be gathered for analysis. It adheres closely, is rapidly replaced when scraped off, and does not easily flux away. This film covers impure aluminum at ordinary temperature, and it is claimed that aluminum alloys of small percentage are troubled with the surface film. In pouring for aluminum-iron castings there must be only one flow: the molten metal is encased in a skin which retards it, and would hinder the union of two streams in the mold.

Being electropositive to all other metals used in the arts, aluminum soldered joints are troublesome. Electrolytic action sets in, especially when the joint is in contact with water, and the metal at the joint disintegrates. For this reason soldered joints are unsatisfactory.

Many solders for this metal have been recently patented. M. U. Schoop mentions his collection of 50 as being incomplete. Most of these inventions specify a flux that will remove the troublesome film. The solder is generally an alloy of aluminum with zinc, tin, lead, nickel, copper, or silver, or any two or more of these metals in varying proportion. The softer of these solders are fluxed on with zinc chlorid, mercuric chlorid, tallow, etc.; the harder solders are fluxed with fluospar, borax, lithium chlorid, etc.[2]

Dr. Richards has invented a self-fluxing solder of a tin and phosphorus alloy. The phosphorus either reduces or dissolves the film that protects the aluminum surface, and the tin alloys with the clean surface. This solder is extensively used. The present composition of this solder is 29 parts tin, 11 zinc, 1 aluminum, and 1 phosphor-tin.[3]

M. U. Schoop, who has also done considerable research work in soldering, has patented a flux. It is a mixture of fluorides of

[1] *Iron Age*, Dec. 31, 1903.
[2] "Die Gewinnung des Aluminiums," A. Minet.
[3] *The Metal Industry*, 1906, p. 22.

calcium, potassium, or boron and the chlorids of alkali metals, and is covered by British Patent No. 24283, Nov. 26. 1908.[1] This flux may be used before soldering or the cleaned metal may be welded without soldering.

The softer solders are often too weak for good work. All of the solders seem liable to electrolysis. The flux, in a general way, may vary in constitution, should not contain water, and should have a moderately high melting point. It should attack the film, but not the metals. Apparently none of the solders can be guaranteed to last indefinitely on account of electrolysis.

Prof. O. P. Watts,[2] of University of Wisconsin, says: "There has been considerable trouble with solders containing tin and possibly with some others. In some cases destruction may have been due to electrolytic action, but in others it appears to be due to a slow diffusion of the tin in the solid state, resulting in the formation of a layer of a very brittle alloy of aluminum and tin, so that the joint breaks. This is a slow action and may require a year or more for its completion."

Aluminum, as can be guessed by its properties, is a weldable metal, but the tenacious film prevents the natural flow. Accordingly, a flux such as suggested by Schoop is used to clean the surfaces. The pieces of metal to be welded cannot be heated above about 600 deg. Cent., because they will be hot-short.

In 1906, W. C. Heraeus,[3] of Hanau a. M., exploited a method of welding aluminum that resembles the smith's treatment of malleable iron. It appears, however, that Heraeus' discovery was antedated by the work of Mrs. Emme of this country, who welded aluminum without melting it as early as 1897. Mrs. Emme sued Heraeus for infringement of patent in 1902, won her case, and was afterward bought out by him.[4] The method as described by M. Minet[5] is as follows: The two pieces of aluminum to be welded are polished carefully around the ends, and the surfaces to come in contact are polished. They are then heated with an oxy-hydrogen blow-pipe or Bunsen flame to the proper temperature, 400 deg. C. When this correct temperature is reached, the two pieces are pressed against each other

[1] *Electrochemical and Metallurgical Industry*, Jan., 1909.
[2] Special Information.
[3] *Iron Age*, Nov. 22, 1900.
[4] Special information.
[5] "Die Gewinnung des Aluminiums," A. Minet.

and are hammered and worked as in ordinary welding, the t
perature meanwhile being kept the same. The metal fl
together at the weld. The success of the operation depends
heating in a complete reducing flame to keep the surfaces bri
and on maintaining the proper temperature. It would tak
skilled workman. Upon cooling it will be found that the j
will withstand concussion tests and sharp changes of temp
ture. Dick patented a somewhat similar process in 1900.

The limitation of this practice in welding is obvious. I
not easy to keep the metal ends in a reducing atmosphere,
they will oxidize rapidly at welding heat in presence of oxy
And, besides, aluminum is a rapid conductor of heat and,
copper, the heat will travel from the joint unless the flam
very hot.

Cowper-Coles has also done good work in welding alumin
He has devised a machine in which the bars of aluminum, clea
and faced off square, are placed and clamped. The bars
heated with a benzene lamp, and when at the plastic point
squeezed together until the metal at the joint forms a considera
blob and the oxid has been forced out of the junction. T
weld is then quickly quenched with a jet of water and at
same time a screen shuts off the flame. This contrivance of
inventor makes a weld that does not have to be worked.

Schoop's method is not dissimilar to these three just describ
only he cleans the oxid with a dissolving flux before weldi
Thus his process does away with the difficulty of cleaning
metal and keeping it clean; the rapid conduction of heat is sti
difficulty.

This latter property of aluminum, its high heat conductivi
is of least consequence in the oxy-acetylene welding proce
where the estimated temperature of the flame is 3600 deg. Ce
This welding process is especially adapted to aluminum, tal
less time, and is sure. The metal pieces need no preliminar
cleaning, though if the body of the pieces is large, as with mo
cases, it is best to heat the whole casting over a gas flame. T
because of the expansion and the rapid conduction of heat fr
the fresh weld. The operator plays his flame directly on t
fracture, using a small melt bar of aluminum to fill up the bre
and to reinforce the weld. Aluminum melts and behaves li
solder under the flame. The operator gets a good melt at t
break and works the soft metal in and out with the end of his m

bar. This prevents the solidification of any of the oxid film in the body of the piece.

This weld gives a cast aluminum reinforcement that is stronger than the body of the piece because it can be reinforced. There is no reason why this system of welding aluminum cannot be applied in all instances where aluminum is to be welded. There are *two precautions* necessary. Aluminum melts at 655 deg. Cent.; the temperature of the flame is at least 2000 deg. So the operator must take care that he does not get his metal too hot, or it will run away from the weld. (In the case of mending motor cases, the fracture is placed in a horizontal position and backed with asbestos paper.) Also, the operator should not use the customary high-oxygen flame. If he does his aluminum will scum.

As for strength of the welded joint, Cowper-Coles,[1] who tested twelve consecutive welds of bars, claimed that the metal had not deteriorated. All of the bars broke outside of the weld, and also outside of the range of high heating. There is no doubt, however, that working the metal at the weld is advantageous, just as it is with iron, etc.

Conclusion.—From the foregoing, it is plain that aluminum articles must be either welded or riveted—not soldered. It is likely that the manufacturers will soon begin to use this welding property of aluminum more extensively. Riveted ware is unsatisfactory, because the metal is too soft unless alloyed. From the fabrication of kitchen ware to the building up of light, strong metal frames, such as for automobiles, welds would be ideal joints.

COPPER

Copper is one of the oldest, if not the very oldest, metals of history. It was used almost entirely as an alloy with tin or zinc, until recent times. The aborigines of North America, however, found the pure metal already smelted for them on the shores of Lake Superior; and the tools they used we find to-day, made of nearly pure metal, mistakenly said to be "tempered by a lost process."

Pure copper melts at 1080 deg. Cent., is fourth in ductility, and sixth in malleability.[2] If free from certain impurities, such as

[1] *Electrochemist and Metallurgist*, Nov., 1903.

[2] Prechtl.

sulphur and carbon, it becomes plastic above red heat. Under an oxidizing flame it will burn or scale, and part of the scale will be absorbed by the metal surface.

It is a curious fact that, though copper is a weldable metal, as appears from its properties, it is hardly ever welded. The common method of joining copper, brass, and bronze has always been to solder, braze, or rivet the pieces. The welding property is occasionally mentioned,[1] but most metal workers are ignorant of the possibility. While the effect of impurities on the welding property appears not to have been gone into, we may presume that the same substances that cause red shortness and assist in oxidation are also detrimental to welding; and that electrolytic and Lake copper, being nearly pure, are also most weldable. "Over-poled" copper, containing carbon, and copper smelted from sulphid ores are red-short, and generally unworkable.

The fact that the welding of copper is almost an unknown art is strikingly shown by the fact that, in reply to the query of a correspondent, the editor of a leading technical publication recently replied as follows: That copper was not weldable; that it flew to pieces if hammered when hot; and that it burned rapidly at welding heat, and would not braze perfectly.

The flux for copper welding usually contains borax or boracic acid and a phosphate salt. One flux recommended is two parts sodium phosphate and one of boracic acid;[2] another is one part yellow potassium prussiate and twenty parts of borax.[3] A pinch of rosin is sometimes added to the flux. When using a phosphate in the flux care must be taken not to bring the copper in contact with free carbon, because copper phosphate will form and will prevent sound welding.[4]

To weld, the metal is heated to redness, when it becomes plastic. The calcined flux is sprinkled on the surface and the pieces are then joined at a yellow heat and hammered together as in iron welding. When using a phosphate flux, do not touch the copper with coke or charcoal. A gas or oil flame is preferable, or the pieces can be heated in an electric welder or with a high-temperature torch. An ordinary hammer and anvil can be used, but on account of the rapid conduction of heat away from the

[1] *American Machinist*, Oct. 23, 1902; Schnabel's Metallurgy, p. 1.
[2] *American Machinist*, Sept. 25, 1902.
[3] *Ibid.*
[4] *Ibid.*

joint, a piece of brick or stone can be substituted for the anvil and a wooden mallet for the iron hammer. Copper at a red or yellow heat is very plastic, if not red-short. So it is well to upset the metal considerably at the joint to allow for working with the hammer.

Copper is welded by the electric process, and a melt-weld can be made with the hydrogen or acetylene burner. But in either case it has been shown that the fibrous structure is destroyed and a crystalline joint occurs. As with wrought iron, the copper weld must be hammered or drawn to restore the fiber. Copper welding is generally considered unsatisfactory, soldering and brazing being preferred, as either can be done below the critical temperature of crystallization.

The smith welding of pure copper is considered more difficult than the smith welding of wrought iron. And because pure copper is inferior in strength to pure iron, is it unlikely that the welding property will ever be generally taken advantage of. But the knowledge that copper can be smith welded and that the welds can be made of 100 per cent. strength. may be occasionally found to be useful in the arts.

NICKEL

Nickel is a metal of secondary importance. Its principal use is in nickel alloys, notably nickel-steel, in plating, in coinage, and in the chemical reductions which call for apparatus made of a metal of inertness similar to platinum, but of greater cheapness.

The pure metal is harder than iron, melts at 1451 deg. Cent., slightly below iron, and is malleable and ductile. It resembles iron in being plastic at a bright red or white heat, and is readily weldable at that temperature. As the ordinary nickel of commerce is quite brittle, due to its impurities, it is seen that it will not weld. The welding property of pure nickel, however, is of importance in nickel plating and in making seamed nickel tubes.

One of the chief objections to nickel plate is its tendency to scale or peel off. Electroplated nickel-iron cannot be drawn, bent, or hammered with safety, and frequent changes of temperature will also tend to crack the nickel surface.

Theodore Fleitmann, of Iserlohn, Germany, took out a patent

a number of years ago for making nickel-plated iron by mechanical means. Sheets of nickel and iron were heated to welding heat in an atmosphere of hydrogen, after having been polished and fluxed. They were then welded between rolls, without coming in contact with the air. By this method the natural tendency of both metals to oxidize quickly was prevented. At the welding heat the metals alloyed at the contact surfaces, and a plate was produced that could be rolled without detriment to the nickel surface.

In 1903, Thomas A. Edison took out a patent for a somewhat similar idea. The difference was that his nickel was electrolytically deposited, the plate was raised to redness in hydrogen gas by electric current, and then rolled. At first Edison plated iron sheets in a nickel solution, piled them together in a clay or cast-iron retort, and raised them to bright redness in a hydrogen atmosphere. At this temperature the metals alloyed and knitted at contact. They were cooled below oxidizing temperature in the same atmosphere before a new change of plates was admitted. Later, Edison improved his process by making it continuous. The iron, in a roll, was passed first through a chamber of hot hydrogen, which reduced all oxids and gave it a fresh surface. From this first chamber it passed into a cooling chamber of the same gas, then through the nickel bath, and the wash-tank; thence through a third hydrogen chamber, where it was raised to welding heat; and lastly to a cooling chamber of hydrogen. The speed was gauged to allow each step of the operation sufficient time.[1]

In 1905, the Standard Welding Company, of Cleveland, exhibited tubes of pure nickel welded electrically. The tubes were strong and the seam was invisible. The present demand for such tubes comes from automobile makers, rubber manufacturers for their end tubes, and industrial chemists for non-oxidizable tubes, retorts, and crucibles.

WELDED PRODUCTS

A great variety of tools, appliances, and parts are welded in some stage of their manufacture. Where pieces of metal are to be joined, welding is the first resort, soldering a poor alternative. As welding is itself a simple process, the chief difference lies in the machinery necessary for different work. In a work of

[1] *The Metal Industry*, Aug., 1904.

limited scope it will not be necessary to go into the details of the stock welds, but a number of the most important will be mentioned.

The processes of manufacture are in many cases adaptations of the recently discovered processes of welding. The electric process is far ahead for repeat or "stock" welding. The hot flames are best for job work, but are beginning to compete with electricity for "stock" work. Thermit is used mostly for job welding or repairing, but can also be applied to continuous rail or pipe joining.

Wrought-iron Pipe.—Pipe welding is about 100 years old, and at this writing the manufacture of welded wrought-iron pipe consumes a large percentage of all the wrought iron made. The first pipe was heated over a coke fire and lap-welded in sections. After the Napoleonic wars gun barrels were a drug on the market and came to be used for water piping. This supply seemed to stimulate the demand, and soon after important inventions began to assist and simplify the original primitive methods. James Russell, who substituted the butt for the lap-welded pipe in 1825, may be called the father of the pipe industry.

Wrought-iron pipes are made in a number of ways. The original lap-weld is still used for its strength. Most pipe is butt-welded from long scarfs of iron, heated in a gas or coke oven, bent round, reheated, and then welded by being drawn over a mandrel and through a die of slightly lower caliber than the pipe. In this way the edges are squeezed together on the outside, while the mandrel pressing on the inside completes the weld. A recent invention is pipe made from a spirally wound and welded strip of iron. Weldless drawn-steel tubing is also finding a market, but so far welded pipe has proved to be cheaper. The process is now a continuous one; and electric welded pipe is now on the market.

Welded pipe is made in sizes of from 1/8 inch to about 30 inches internal diameter. Larger than this, it is generally riveted. The iron must be of very good quality, quite pure, and low in sulphur and carbon. Fifty thousand pounds per square inch tensile strength is as high as it is safe to try to use, as stronger irons than this give weaker welds. High-carbon irons and steels should never be used for pipe, though their initial strength is great. Such metal welds poorly and may easily pull apart at the weld under great pressure.

[redacted]

Miscellaneous. [redacted] Cap screws have larger heads of rough steel welded on by electricity. There are children's hoops, primers, chasers, three-[illegible] blade blades, garden rakes, boiler tubing, axe-blades, shotgun [illegible], iron rings, wire fences.

[illegible] best grade of American anvils are made of a hard quality [illegible] plate welded on to the top of the block, while the anvil

[illegible] Manufacture of Chain," L. B. Powell, *Iron Age*, Jan. 5, 1905.

horn is also welded on. The best plows are made of three-ply welded steel plate with a welded toe to resist the wear of cutting. The three-ply plate is soft centered.

Besides these older products, many of the industries which have recently sprung up are using welding apparatus for making minor parts of apparatus and machinery—the joining of a durable well-wearing metal on a softer body, one metal to another, or one special casting to another, so as to avoid the use of intricate patterns. Ship-builders weld constantly, though it is bad practice to weld a vital part. Smith welding is used much less than formerly on manufactured articles. The patent welding processes are cheaper, quicker, and safer and are superseding the old hand method.

PART II

ELECTRIC WELDING

General

Electric welding processes have been used commercially since about 1880, when Elihu Thomson brought out his low-pressure resistance machine, invented about 1877. In recent years several processes, notably that of Thomson, have become widely known for their successful application to rail welding and to repeat welding of stock pieces in manufactories, such as wheelbarrow spokes, wagon frames, printing chases, etc. Though the several processes in which electric current is used in welding are unlike in apparatus and application, the basic idea of each process is to produce the welding heat by means of resistance to an electric current. The different processes are:

1. La Grange-Hoho. Welding heat produced by resistance in an electrolyte.

2. Zerener. Welding heat produced by an electric blowpipe consisting of an electric arc deflected by a magnet. Welding material introduced in shape of a melt bar.

3. Bernardos. Welding heat produced by an arc between the carbon negative electrode and the metal to be welded. Welding metal is introduced in the shape of a melt bar.

4. Slavianoff. Welding heat produced by an arc between a metallic electrode and the metal to be welded. The welding metal itself forms one electrode.

5. Thomson. Welding heat is generated by internal resistance at the point of contact of the metals to be welded.

The electric welding processes, especially the last, have followed the adoption of the oxyhydrogen, gas, and oil flames, and slightly antedate the oxy-acetylene and thermit welding methods. The arc-welding systems followed the commercial introduction of the arc-light in 1881. The internal resistance method was earlier suggested by the experiments of Joule and Moissan. In 1856 Joule welded a bundle of iron wires by burying them in

charcoal and heating them with current. While in Moissan's furnace the resistance of a closed metallic circuit (as well as the arc-furnace) generated the heat for melting refractory metals and for making alloys.

The Thomson process, the oldest and still the most important, will here be last described.

THE LA GRANGE-HOHO PROCESS

This process is well called the "water-pail forge." It comes from Belgium and has scarcely been tried out. The metals to be heated are fastened to the negative pole of the circuit and immersed in a bath of an electrolyte, such as potassium carbonate solution. The current when turned on flows from the positive pole through the solution, and returns by way of the metal piece as a negative terminal. The solution begins to decompose, depositing hydrogen on the metal piece in a thin film. The metal piece becomes red- or white-hot, and is protected from the solution by the hydrogen film. As soon as the proper heat is reached, as told by the color of the metal, the pieces are taken out of the solution, and welded or hammered together on an anvil with a hammer.

The advantage of this process is that the metals are perfectly cleansed from grease, dirt, and oxid by the bath, and are protected by the hydrogen film.

The disadvantage is that the heat is not easily controlled. While the working of the hot metal must be done by hand in the air where the metal will soon oxidize.

This process is not likely to have a wide industrial application.

THE ZERENER ELECTRIC BLOWPIPE

Werderman applied the high heat of the electric arc to melting and welding metals. His apparatus was an ordinary flaming arc, the carbons being inclined toward each other. The flame of the arc was directed away in a point from the carbons by means of a blast of air. In a more recent development by Zerener the repulsion of an electromagnet in series with the arc is used to direct the arc against the work. The following points have been charged for and against this process.

1. What is much cheaper than either the oxy-hydrogen or

FIG. 10.—Zerener blowpipe apparatus.

both carbon, and the metal to be melted was placed between the
uniform in the path of the arc. De Meritens substituted the
metal itself for one of the carbons; and later Bernardos, a Russian,
introduced the process. Coffin has taken out similar patents
in America. The Bernardos process has been known in Europe
no more than twenty years, and has recently been introduced

THE BERNARDOS ARC-WELDING PROCESS

This arc-welding process is an evolution of the electric furnace. In the electric furnace of Moissan and others the electrodes were

o this country. Welding heat is obtained by the electric
. The metal to be welded or melted is the positive pole.
e negative pole is a carbon pencil. The current used is
ect, of 100 to 300 volts, and 600 to 1000 amperes. The
tal to be welded lies on a metal table to which the positive pole

FIG. 11.—Operator welding with Bernardos arc process.

clamped. The carbon negative is placed in contact with the
tal and the current is thrown on. The carbon pole is then
thdrawn 2 to 4 inches, and an arc is sprung, which follows the
rbon wherever the carbon is manipulated by the operator. The
ater part of the heat of the arc, about 3500 deg. Cent., is gen-

erated in the metal or is reflected back on the metal from the arc. The apparatus used is as follows:

1. Generator of direct current of 100–300 volts and 600–1000 amperes.

2. A metal table on which to place the work.

FIG. 12.—Operator welding with Bernardos arc process. (Courtesy Proceedings of the Engineering Society of Western Pennsylvania, May, 1909, C. B. Auel.)

3. Leads, switches, and controlling apparatus for the current carbon pencil.

4. Protective apparatus for the workman.

Apparatus and Current.—*The Generator.*—It is claimed by the advocates of this system that good results cannot be ob-

tained unless current of ample volume and pressure be used. Current from power wires is generally inadequate. It is best to have a special dynamo of not less than 75 to 100 kw. For reasons given below, the current should be direct. Where the current supplied is alternating, a direct-coupled motor-generator is used to transform to direct current. The motor-generator coupling must be flexible to prevent the armature from burning out. This generator will be much the most expensive part of the apparatus—costing more than all the other mechanism.

Direct current is much better and cheaper than alternating. As is well known, the greatest heat is found near the positive pole

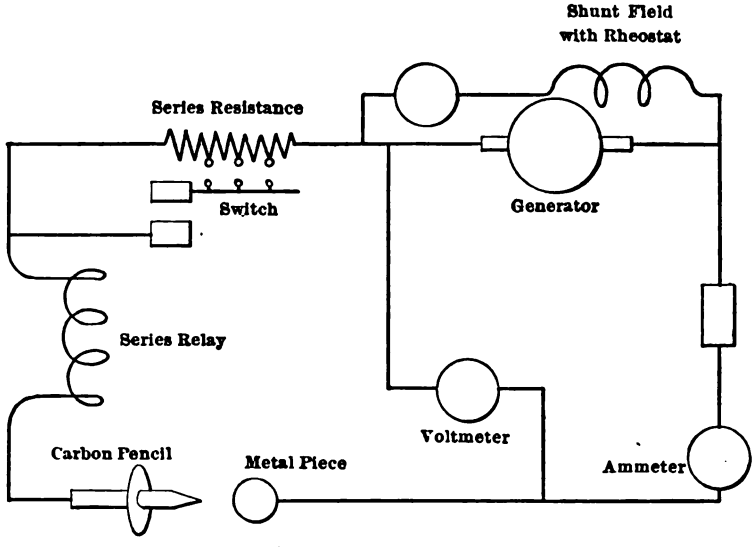


FIG. 13.—Diagram of Bernardos arc welder.

of the arc. For this reason the metal object to be welded is made the positive pole of a direct current. If it were the negative pole, more heat would be lost and the carbon from the pencil would enter the weld and harden the metal. While if an alternating current were used, some of the carbon would enter the hot metal, while the weld would not receive more than half the heat of the arc.

Table, Switches, Controlling Apparatus, Carbon.—The table which holds the work is of cast or wrought iron. The metal to be welded is laid on the table, and it is supposed that the contact between table and metal will be sufficient to carry the current.

If the piece of metal is small the positive lead had better be clamped directly onto the metal instead of the table.

The switchboard contains a single-throw switch and a rheostat connected with grids. Or the rheostat may be made of water-barrels with insulated sides and a terminal plate for a bottom. The other terminal is also a metal plate suspended over the barrel. It is lowered in and out of the water of the barrel. The trouble with barrel rheostats is that the water is liable to boil over under continuous usage, while the barrel hoops will rust rapidly. Circuit breakers should be used to prevent the armature from burning out, in case the operator accidentally short-circuits by touching his carbon pencil to his work.

The carbon pencils are made in sizes of 1/4-inch to 1 1/2-inch diameter by 6 to 12 inches long—of sound carbon. The carbon pencil is fixed into an insulated handle. Midway on the

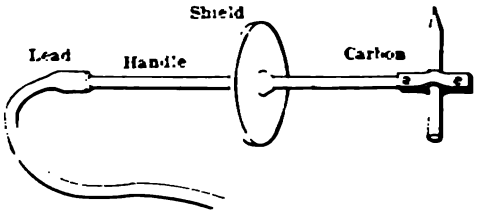


FIG. 14.—Carbon negative pole and shield.

handle is a round shield to protect the operator from the flame of the arc and from sparks (see Fig. 14).

Workman's Protective Apparatus.—Under this head come rubber gloves, a leather or rubber suit or apron, a hood of cloth, stovepipe or wood for the head, and a pair of glasses for the eyes. Bear in mind that the operator is manipulating a current of high voltage and also an arc of great heat and dazzling light. A stovepipe hood for the head is rather unsafe because of the danger of shock. The eye-glasses had better be double, of red and green or red and blue glass, because the light is violent.

Operation.—In practice the metal piece to be welded is often clamped on to a table to which the positive lead is also clamped. However, in many cases the table is di[illegible]ly and the positive lead clamped direct[illegible]e welded. To start the arc the carb[illegible]nto

This cutting property of the Bernardos arc is somewhat similar to the oxy-acetylene torch (see page 37). The arc is not so efficient as the acetylene torch, however. The latter makes a cleaner and smaller cut and clears the metal away as the flame advances. The cutting arc has been used to cut down the steel piers of the Ferris wheel, for thawing the taps of frozen-up blast furnaces, for cutting off parts of castings, and also for mending cracks in castings.

Mr. Auel[1] gives the following table of data for the cutting arc as approximate:

TABLE 8.—BERNARDOS PROCESS, BURNING HOLE IN WROUGHT-IRON PLATE[2]

Line volts	Amperes	Volts across rheostat	Volts across arc including carbon
120 (open circuit)			
98	430	23	72
102	400	22	81
104	370	20	86
85	1000 (kick)	24	60
87	1000 (kick)	35	63

Mr. Hills gives the following cutting and welding data:

TABLE 9.—CARBON ELECTRODE CUTTING AND WELDING

Size.	Time burning out and preparing.	Time to weld.	Amp.	Volts.	Kw.-hr.
2″×2″	3 minutes	10 min.	400	65	5.4
3″×3″	7 minutes	20 min.	400	65	12
4″×4″	10 minutes each side. 1 hr. 15 min. to complete welding and cutting.	25 min.	400	65	34
5″×5″	15 minutes each side. 2 hr. complete welding and cutting.	40 min.	450	65	58 1/2
6″×6″	18 minutes each side. 2 1/2 hr. complete welding and cutting.	40 min.	500	65	81

[1] "Arc Welding," C. B. Auel, *Proceedings of the Engineers' Society of Western Pennsylvania*, May, 1909; presented before the Society, April, 1909.

[2] Size of hole = 1 3/4 inches diameter by 1 1/2 inches deep. Size of carbon = 1 1/2 by 6 inches. Time = 3 minutes 30 seconds (includes 45 seconds for reversing plate).

THE SLAVIANOFF ARC WELDING PROCESS

The Slavianoff or metallic electrode process of arc welding utilizes the melt bar or the welding material as one electrode of the arc, the other being the work itself. The movable electrode is called the welding pencil. In this process Slavianoff sought to overcome the troubles experienced from hard welds due to carbon in the molten metal. However, his method, although a success in this direction, was not commercially developed until welding fluxes were introduced.

Fluxes may be applied in a number of different ways, but the best method yet developed is that of coating the exterior surface of the welding pencil itself. When applied in this way the coating may be made to serve two useful purposes providing it contains sufficient refractory material.

The effect of refractory coatings on the welding pencil in facilitating the work of welding was first discovered by Kjellberg in Sweden,[1] who took out patents on the coating of a welding pencil with a refractory flux.

The action of a refractory flux coating is twofold:

1. It permits the electromagnetic effect of the welding current to act upon the molten metal.

2. It applies flux to the weld at a rate that adjusts itself perfectly to that of the melting of the welding pencil.

It is by virtue of the electromagnetic action of the current in connection with the refractory coating that overhead welding is possible. The theory of this action in overhead welding was first explained by Otis Allen Kenyon. It rests upon two fundamental principles:

1. Around and within every current-carrying conductor there exists a magnetic field of force, the equipotential lines of which are concentric with the conductor. This force is a maximum at the periphery of the conductor and decreases from there in both directions.

2. A current-carrying conductor in a magnetic field is acted upon by a mechanical force the magnitude of which is proportional to the product of the values of the current and the magnetic flux.

By virtue of these two principles, if two or more parallel con-

[1] The Electric Welding Company, New York, controls the patents for the American Continent.

ductors carry current in the same direction they will be drawn together, while if the currents are in opposite directions the conductors will be repulsed.

Now if it be assumed that a single current-carrying conductor be made up of an infinite number of parallel conductors, then by the same laws there will be a mechanical force exerted upon each elementary conductor tending to draw it toward the center. This action is equivalent to a contracting force and is called "pinch effect." The magnitude of this contracting force is proportional to the square of the current.

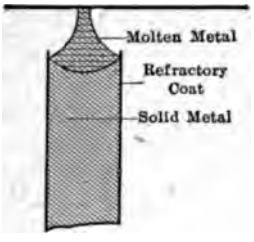


FIG. 15.—Effect of pinch effect with refractory coating.

Although pinch effect is present in every current-carrying conductor, it is only perceptible in liquid or plastic conductors.

In overhead arc welding pinch effect is utilized by covering the metallic electrode with a refractory coating which acts as a crucible and retains a small amount of molten iron on the end of the electrode. This molten iron being subjected to the pinch effect of the current through the arc is squeezed toward the center and since it cannot move inward to the solid iron of the electrode, it must move outward to the metal to be welded and it does this even against the force of gravity.[1]

The electromagnetic effect of the welding current through the arc manifests itself as "pinch effect." This action of the magnetic field is only exerted upon current-carrying conductors and is a function of the current in the conductor. Magnetic fields, due to solenoids or external coils, also affect the arc, the effect depending upon the position of the coils. A coil wound around the electrode with its longitudinal axis coincident with that of the electrode has no effect whatever upon the arc. If such a coil be inclined to the axis of the electrode it will deflect the arc, the magnitude of deflection depending upon the angle which the coil makes with the electrode, being a maximum at 90 degrees.

As far as the iron itself goes, it is non-magnetic above 750 deg. Cent. and therefore is not acted upon by virtue of its magnetic qualities. Whatever action a magnetic field exerts upon molten iron in a welding arc, is due to the current in the arc and would be

[1] Scientific Welding, The Electric Welding Co.

just the same for copper or any other kind of metal arc as for an iron arc.

Apparatus.—The standard apparatus for the modern Slavianoff process consists essentially of three elements:

1. A suitable source of electric energy.
2. An electric circuit for conveying energy from the source to the work and a controller for manipulating the energy.
3. Welding clamps and pencils.

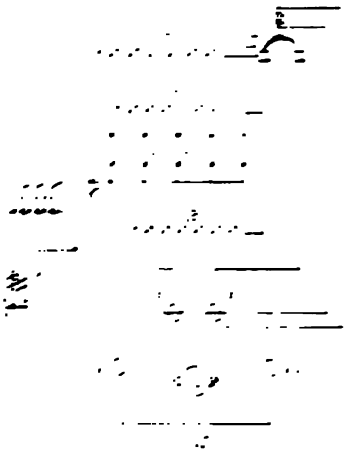
Generator.—Any kind of direct-current generator, providing it furnishes sufficient power, may be used for electric arc welding, although it is desirable wherever possible to use generators that are designed to suit the special conditions under which they are to operate, since such machines minimize the skill required by the welding operator. One of the most important companies uses two distinct systems of energy supply.

1. Constant potential.
2. Constant current.

The constant-potential system is used by practically all welding concerns and in most cases the generator is an ordinary lighting dynamo with a voltage varying from 60 to 100 or more. With the constant potential system and a well-designed generator, any number of arcs may be operated in multiple, providing suitable controllers are used.

The actual e.m.f. across a metallic arc varies from 15 to 30 volts depending on the current, while the voltage of the generator in the constant-potential system is never chosen below 60 and seldom above 100, although in rail welding, 500 volts are sometimes used. The difference between the generator voltage and the arc voltage must be consumed in resistance; therefore, from the economy standpoint, it is desirable to use a low-voltage generator. However, a resistance in series with the arc greatly improves its stability and if we attempt to eliminate series resistance in the constant-potential system, the arc becomes so sensitive and unstable that welding cannot be performed. Since both economy and stability of the arc are desirable, it is a great disadvantage of the constant-potential system that economy is gained by sacrifice of stability and stability by sacrifice of economy.

The constant-current system does not possess the inherent disadvantage of the constant-potential system. In this system no rheostat is used and therefore resistance losses are eliminated and the stability of the system depends directly upon the design of the



The Electric Welding Co.

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Controllers.—The constant-current system requires no controller. In the constant-potential system controllers of many different types are used. If the welder have sufficient skill, it is possible to use nothing more than a grid resistance or a water rheostat in series with the arc. However, a crude system like this is not advisable since it requires great skill on the part of the welder and in any case makes his work more difficult. The prime object in the design of some controllers is to relieve the generator from sudden fluctuations of load, little or no direct benefit being received by the welder. The Electric Welding Company uses a series resistance to take up a definite portion of the generator voltage and a series reactance, *H*, to minimize rapid fluctuations in the current. (See Fig. 16.) They also use an impedance, *D*, equivalent to that of the arc which is shunted across the arc terminals. By means of this equivalent arc it is possible to adjust the current in advance of beginning the actual work of welding. Once the arc is struck, the equivalent arc is dropped from the circuit by the relay, *G*, and the contactor *E*.

One company recommends that wherever possible, the generator be located in the power house with other electric machinery where it can be looked after by the regular power plant attendants. In such cases the shops are wired so as to permit the operation of portable controllers at various points throughout the works.

Welding Pencils.—The welding pencil is made of the material to be deposited in the joint and corresponds to the melt bar in the Bernardos process and the oxy-acetylene process. Upon the composition of these pencils depends largely the success of the weld. There has been great difference of opinion on this subject. Some welders claim that the composition of the electrode is of little importance; others claim that pure Swedish iron is the best that can be obtained for all purposes. However, the best results have been obtained by those who use welding pencils of composition chosen in accordance with the requirements of the work. As yet it is impossible to give specific information on this subject, because those who have investigated it do not choose to reveal the results. However, it may be said that the company which has had greatest success in the application of special welding pencils for different kinds of work, makes a general practice of using a commercially pure iron as a basis and adding to this small percentages of other metals which give to the weld the quality

desired. However, one author[1] claims that steel should be welded with steel pencils containing carbon, the carbon content of which is from 5 to 10 points higher than the pieces to be welded.

To give an idea of what may be had on the market, we describe three standard types of welding pencils as made by the The Electric Welding Company.

Type 1. *Machine Welding Pencil.*—Suitable for hard cast iron and steel. These may be cut to any length between 8 and 15 inches.

Type 2. *Cast Iron.*—Especially suitable for all kinds of cast iron. These can be supplied in lengths from 8 to 12 inches up to 7/32 inch in diameter, and from 8 to 30 inches for diameters above 7/32 inch.

Type 3.—High-class steel plate welding pencil cut to any length. This pencil is the one recommended for boiler welding, however, Type 1 can also be used. Indeed Type 1 will give results equal to the usual requirements of most boiler work.

Welding Fluxes.—The composition of welding fluxes is much more important than that of the pencils. Indeed, in many cases it is possible to use commercially pure iron pencils and insert the alloying metals into the flux. The composition of fluxes, like that of welding pencils, is jealously guarded by those who have investigated the subject. Speaking of the fluxes that are applied to the surface of the electrodes, they are generally mixed dry and applied to the pencils by making them into a paste with water into which the pencils are dipped. Some of these fluxes are ready for use immediately after dipping and others must be set away for several days to dry out and set thoroughly.

To give an idea of what fluxes are obtainable in the market, we again describe the three standard types marketed by The Electric Welding Company.

Type 1.—Machine welding flux for hard cast iron and cast iron to steel. There are three grades of this flux, namely: Flux for hard welds; flux for medium welds; flux for soft welds.

Type 2.—Cast-iron welding flux.

Type 3.—High-class steel plate welding flux made up for various tensile strengths: 100,000; 75,000; 65,000; 60,000; 55,000: 50,000 and 45,000.

Operation.—In the Slavianoff process, the circuit leads are connected in practically the same way as in the Bernardos

[1] Mr. George Hills, Electric Welding Materials Co.

process, with the exception that the Bernardos or carbon arc should always be operated with the electrode connected to the negative side so as to avoid carbonization of the weld, while in the Slavianoff process, the welding pencil may be connected to either the positive or the negative, providing the pencil is properly dimensioned. However, it requires more skill to weld with the pencil connected to the positive than to the negative side of the circuit.

The metallic arc is very much shorter than the carbon arc, varying from less than 1/8 inch to about 3/16 inch and therefore it requires a steady hand to manipulate it.

In welding, the parts to be joined are clamped in their proper position and both connected to one side of the circuit. The edges or surfaces to be joined are bevelled at an angle of from 30 to 45 degrees. However, they do not have to be farther apart at one end than at the other to allow for temperature expansion as is the case with hot flame and carbon arc welding, where the heat spreads to such an extent that the total heat energy applied to the work is much greater than in the metallic arc process, where the heat is extremely localized and therefore more efficiently used.

The operator begins work by drawing the arc, whereupon the metal immediately begins to flow from the welding pencil into the joint. When a small quantity has thus passed over, the pencil is moved forward at an even and slow rate, thus depositing a string of metal along the joint. By this process the heating is extremely local and no puddling or circular movement is necessary.

The extreme localization of the heat in this process is an enormous advantage, especially where large masses of metal are concerned, as it minimizes stresses due to expansion and contraction. In the case of the oxy-acetylene flame or the carbon arc, which also behaves like a flame, the heat spreads over a considerable area and thus causes sufficient expansion to produce serious temperature strains. Experiment shows that it is not necessary to the welding operation to heat up a large area. Indeed, one writer[1] states that, "it is a matter of observation that a stronger weld is made between metal deposited upon cold metal than when the metal is deposited upon hot metal; that is, the union between the molten drop of iron from the pencil and the metal to be welded

[1] Mr. Otis Allen Kenyon, The Electric Welding Co.

is best when the heating is highly localized and the surrounding metal comparatively cool."

Another great advantage of the metallic arc process is that the operator does not wear a helmet or a pair of colored glass goggles, but holds in one hand a glass screen which he places between his face and the arc when in operation, and lowers each time the arc is broken. Therefore, he is continually examining his work and will do it more carefully than he would were it necessary to remove the helmet each time to look at it. The advantages of this system compared with the Bernardos process are greater adaptability to different kinds of work, less power consumed, higher quality of weld and closer control of the welding conditions.

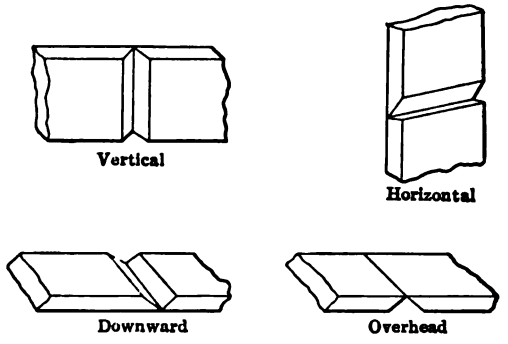


FIG. 17.—Standard welding positions.

The disadvantage of this process, if any, is the high degree of skill required in operation. Indeed it is claimed by some that none but the largest shops should attempt to install their own welding equipment, but should preferably let out the work to welding contractors.

The Slavianoff process cannot be compared with oxy-acetylene in all classes of work. Each has a distinct field of its own. With thin sheet metals below 1/16 inch in thickness, arc welding cannot, at the present time, be used successfully, while oxy-acetylene with skillful manipulation can be used. With plates below 1/8 inch in thickness, oxy-acetylene permits faster work than the arc. However, above this thickness, the metallic arc is faster and the difference between the two increases in favor of the arc as the thickness goes up.

The cost of the metallic electrode process compared with oxy-

acetylene also varies with the character of the work. Generally speaking, it may be said that the welding materials for a given job are the same in both cases and that the cost of labor is the same per day and therefore the labor item per job will depend upon the speed of welding. The first cost of installation is usually in favor of the arc system. The fire risk is in favor of the

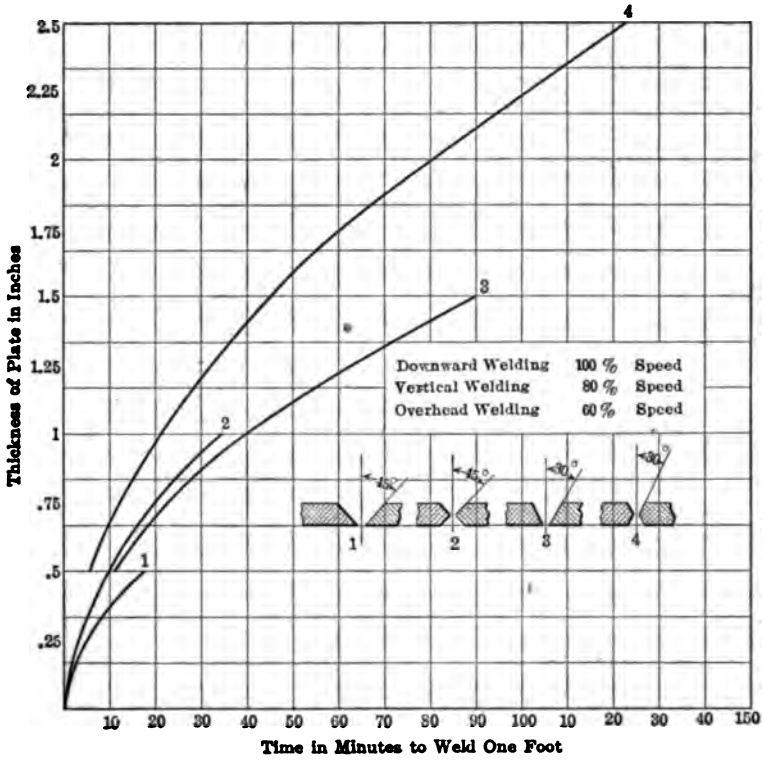
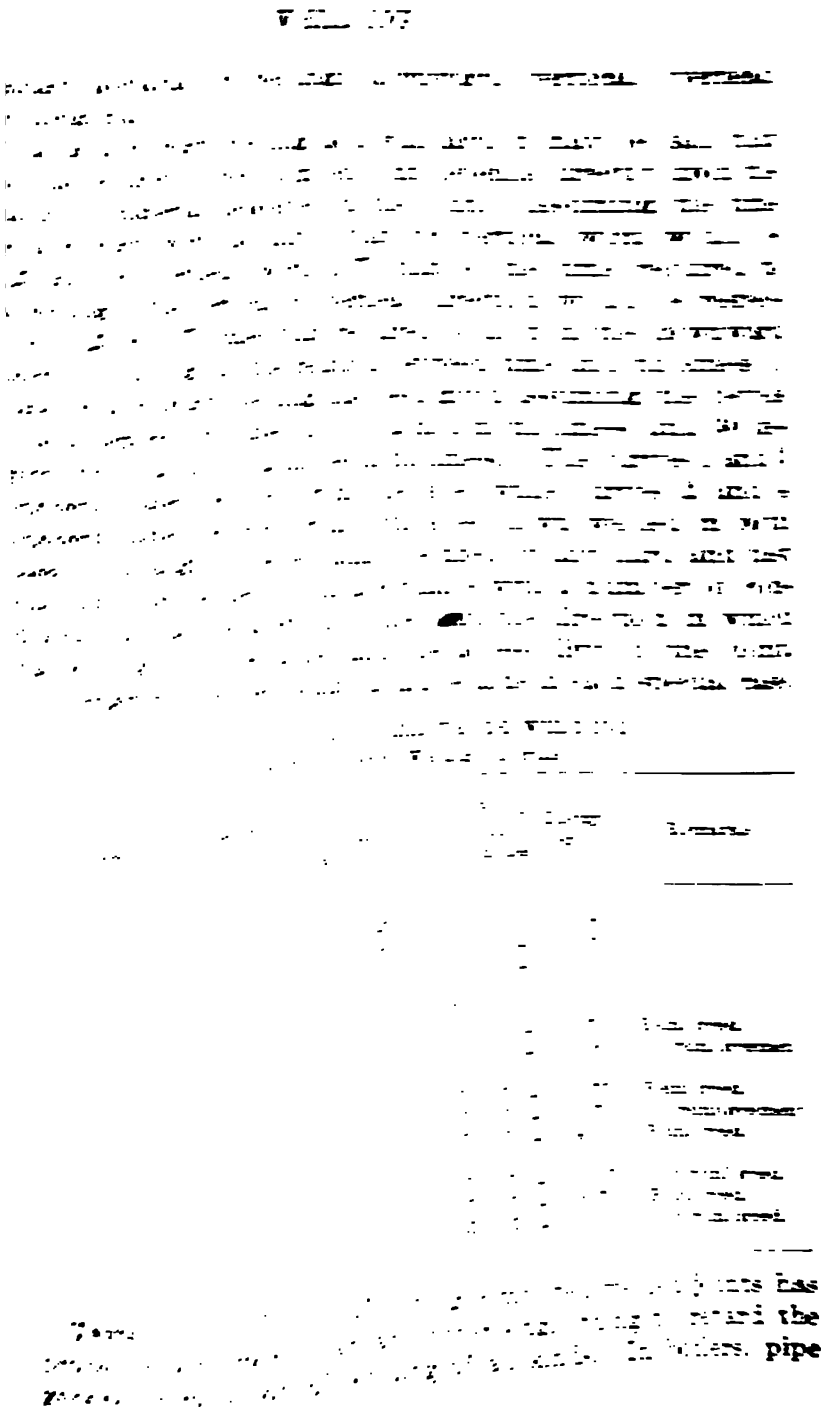


FIG. 18.—Actual time for welding steel plates of various thicknesses. (Courtesy The Electric Welding Co.)

arc system. The cost of energy depends on the conditions; in the one case the energy is furnished by an electric generator and in the other by acetylene and oxygen generators.

The time required to weld depends on a great many factors: the thickness of the piece, the relative angle of one piece to the other, the angle of the bevel at the joint and the direction in which the welding material must be deposited. Fig. 17 shows four



lines, tanks, etc., where test pressure can easily be applied, welding has been taken up and is making rapid progress. However, in other cases, such as tension members of a complicated steel structure, where actual testing of the joints is out of the question, engineers are loath to trust welding as compared with riveting.

It is well known that riveting is inefficient. However, the subject has been widely and thoroughly studied and therefore it is possible to design a riveted joint of known stength, which, if inspected by a competent man, may be relied upon to produce definite results. The efficiency of riveting decreases with the thickness of plate and in any case is comparatively low, while metallic arc welding, when properly done, will give efficiency of 100 per cent. This has been done in test specimens; however, on account of the large amount of inferior welding that has been performed by incompetent welders, engineers are seldom sufficiently impressed by specimen tests to rely upon welding in members that cannot be tested before being put into service.

This condition is not unique with welding. In fact, it obtains even to a more serious degree with reinforced-concrete construction, which, as is well known, depends absolutely upon the faithfulness with which specifications are complied with in the construction and once in place, the weakest kind of construction and the worst flaws may be hidden behind a sound surface of concrete. Nevertheless, concrete-steel construction is making rapid progress as welding will probably also do, when engineers become more familiar with actual results obtained.

The fact remains, however, that it is highly desirable to develop some method of inspection which will permit the determination of the approximate quality of a welded joint. Mr. L. A. Haas of London, England, describes in "The Boiler Maker," April, 1913, a method of testing welded joints by means of kerosene which permits the discovery of the slightest porousness of a joint, which although it may not be an index of the tensile strength of the weld, nevertheless bears a direct relation to the quality of the weld. The following is quoted from his article:

"Kerosene has that insidious creeping tendency, the despair of usual methods of calked riveted seams, as all who have had the misfortune to do with bulkheads in tank steamers can testify.

"The remarkable point about testing in this manner is that the kerosene will come through and stain the outside of the weld, where

[illegible]

[illegible] comparative tests of [illegible] bars electrically [illegible] grades of English [illegible] approximately. He [illegible] for the arc [illegible] bars [illegible] of the original stock.

[illegible] the operator has reason [illegible] near the weld. [illegible] he can use a [illegible] metal welded and [illegible] at present [illegible] welding.

Tables 11, 12 and 13 give the results of tests on boiler plates. In Table 11 the thickness varied from a little less than 1/2 inch to more than 3/4 inch, but the strength seemed to be independent of the thickness. Table 12 shows test made upon plates

welded in different ways. From these tests it is evident that a joint of 100 per cent. strength can be obtained when sufficient material is deposited to allow the removal of all burnt metal. The burnt metal and other deleterious components float upon the surface of the molten drops and when the welder properly manipulates his arc these harmful ingredients are entirely removed from the interior and carried outward on the surface, where they can be cut off with a chisel.

TABLE 11.—TENSILE TESTS ON PLATES

Different Thicknesses of Plates. (The Electric Welding Co.)

The test pieces							Elongation					
Mark	Length	Breadth	Thickness	Sectional area	Stress at yield-point	Tensile strength	In 4 inch	In 8 inch	Contraction of area	Distance of the rupture from nearest end	Distance of rupture from welded joint	Remarks
	Inch	Inch	Inch	Sq. in.	Lb. per sq. in.	Lb. per sq. in.	Per cent.	Per cent.	Per cent.	Inch	Inch	
ES 44	8	1.20	0.82	0.98	26,400	43,200	38.0	29.4	62	2½	.....	Not welded
ES 45	8	1.21	0.81	0.98	24,600	40,400	41.4	26.4	73	1½	4½	Welded
ES 46	8	1.17	0.81	0.95	26,200	42,400	40.1	28.7	65	3½	2½	Welded
ES 47	8	1.18	0.82	0.97	27,600	43,400	38.3	21.4	66	1½	4½	Welded
ES 48	8	1.18	0.81	0.96	27,000	41,200	43.6	24.1	74	2½	4½	Welded
ES 49	8	1.20	0.46	0.55	25,400	40,600	30.8	25.8	68	3½	2	Welded
ES 50	8	1.18	0.47	0.55	29,000	41,200	32.3	18.4	69	2½	3½	Welded

Practice.—The field of arc welding is almost unlimited on account of its great adaptability. This branch of welding is just in its infancy. In fact, very little is known of the relations that exist between the numerous variables that enter into the process. At the present time it is used mostly as a repair process in the hands of skilled operators. Its greatest use is probably in marine work, welding up boilers, ships, hulls, broken machinery, etc. It has also been used to a certain extent in railroad repair shops although the Bernardos repair process has been used more widely on land than the Slavianoff process.

Arc welding is just beginning to be used in manufacturing processes and it will probably not be long before automatic machines will be developed for making arc welds in which the personal equation of the operator will be practically eliminated.

Illustrations herewith indicate what is being done by this process.

Probably the most important piece of arc welding work that has yet been executed, was done by The Electric Welding Company, in welding up the steel lining of the Rondout siphon of the Catskill Aqueduct. This siphon was originally constructed with a concrete lining, but when the water was turned into it, the pressure broke through the concrete where there were mud seams in the rock and lifted the lining above the springing line, thus causing large leaks.

TABLE 12.—TENSILE TESTS ON PLATES. DIFFERENT METHODS OF WELDING[1]

(The Electric Welding Co.)

Numbers on plates	1	2	3	4
Thickness of sample in inches	0.503	0.502	0.502	0.501
Thickness at weld in inches	.....	0.500	0.764	0.517
Width of sample in inches	0.992	0.994	0.996	0.996
Width at weld in inches	.....	0.992	0.997	0.997
Strain at which sample parted	29,770	.....	30,450	30,760
Strain at which weld parted	.....	23,270	.....	.....
Strain per sq. in. of section	59,659	.....	60,900	61,643
Strain per sq. in. of weld	.....	46,915	.....	.....
Reduced thickness in inches	0.318	.....	0.442	0.324
Reduced thickness at weld inches	.....	0.474	.....	.....
Reduced width in inches	0.723	.....	0.886	0.741
Reduced width at weld in inches	.....	0.952	.....	.....
Reduction of area per cent	53.9	.....	21.6	51.9
Reduction of area, at weld	.....	9.07	.....	.....
Length of part in center test piece	8 in.	8 in.	8 in.	8 in.
Elongation, percentage of 6 ft. 2 in.	27-08 43-75	.....	7-29 12-5	17-7 34-37
Elongation, percentage at weld of 6 ft. 2 in.	.....	4-16 6-25	.....	.....

[1] No. 1. Solid plate.

No. 2. Solid plate cut in two and welded flush.

No. 3. Solid plate cut in two and welded flush and built up on one side.

No. 4. Solid plate, welding material applied on one side for about 2 1/2 inches and planed off.

No. 2 parted in the weld. No. 3 parted in the solid plate close to the reinforced welding (which was about 2 1/2 inches in length). Welding material had been applied at the point of fracture but has been planed off in shaping the coupons. This would account for the low reduction of area. Practically no reduction of area at weld. No. 4 parted about 1 inch from where welding material had been applied and planed off.

In order to modify this construction so as to overcome permanently the danger of leaks, it was decided to line a section about 800 feet long with 15-inch 55-pound channels bent into ring form and then lined with concrete. On account of the small diameter of the shafts leading to the tunnel, it was necessary to make this lining in segments which would be joined together in the tunnel itself. Ordinarily these rings would have been

FIG. 19a.—Corroded seam in locomotive boiler.

FIG. 19b.—The seam (Fig. 19a) repaired by arc welding. (Courtesy C. & C. Electric & Mfg. Co.)

Fig. 28.—Welded patch on back leg and bottom of boiler, also reinforcement of throttle. (Courtesy of The Electric Welding Co.)

FIG. 21a.—Welded reinforcement around staybolts in side sheet of firebox. (Courtesy of The Electric Welding Co.)

FIG. 21b.—Welded reinforcement around staybolts in side sheet of firebox. (Courtesy The Electric Welding Co.)

FIG. 22.—Broken rim of cast iron sheave restored with welded material. New metal shown white. (Courtesy The Electric Welding Co.)

riveted with butt straps, but in order to do this, it would have required a large amount of extra blasting in order to provide space

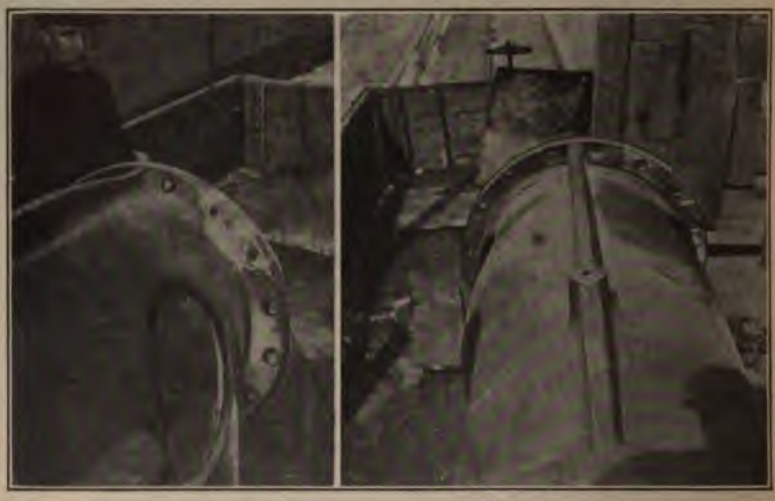


FIG. 23.—Engine frame, broken in shipment, welded in car. (Courtesy of The Electric Welding Co.)

FIG. 24.—Broken lathe, steady rest.

for riveting. Furthermore, riveted joints would have had to be caulked. After making a number of experiments on butt-welded 15-inch channels, the Board of Water Supply decided

FIG. 25.—Lathe steady rest (Fig. 24) repaired by welding. (Courtesy C. & C. Electric & Mfg. Co.)

FIG. 26.—Welder working on steel lining of Catskill aqueduct. (Courtesy The Electric Welding Co.)

FIG. 27.—Leaks in the Rondout Siphon before metal lining was installed.

FIG. 28.—Hauling sections of steel lining into tunnel.

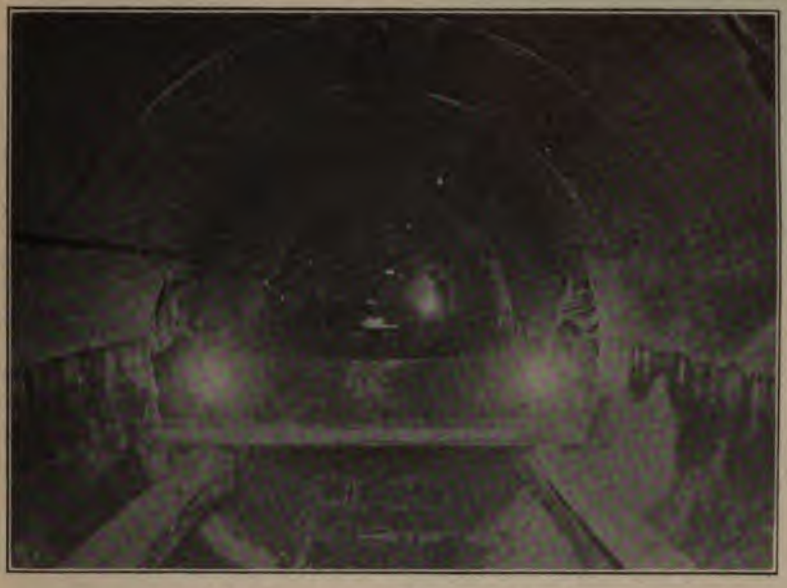


FIG. 29.—Welding steel lining in tunnel. (Courtesy The Electric Welding Co.)

FIG. 30.—Bull riveter in tunnel, welded nose. (Courtesy The Electric Welding Co.)

to permit the joining of these segments by arc welding. The actual work of welding began December 28, 1912, and was completed April 4, 1913. 1818 welds were made with a total length of over 6000 feet of welded joint.

The electric welding plant was installed in the tunnel on a platform 300 feet from the nearest end of the section that was to be reinforced. Adjacent to this platform there was erected the operating platform carrying templates for the assembling and clamping of the segments for welding. It was here that the welding work was done, provision having been made for welding three rings simultaneously, with three arcs in each ring.

In executing the work the steel segments were lowered 475 feet through shaft 3, loaded into a car and hauled by an electric locomotive to the operating platform, where they were assembled into rings on the templates, clamped in accurate relation and welded.

After welding, the rings were handled by an overhead trolley system, and either put into storage or delivered to the erecting car.

The erecting car was equipped with a tipping device, which made the accurate manipulation of the heavy rings in the very restricted space of the tunnel extremely easy. This car was used to transport the rings to the point of erection and to place them for bolting to the rings previously erected. Later the rings were riveted with a pneumatic bull riveter under 80 tons' pressure.

An interesting application of the same welding process was made in connection with the bull riveter. The end of the jaw which held the matrix was too weak to stand the force exerted upon it, and was stiffened by reinforcing with steel deposited on both sides of the jaw as far as the necessary working clearance would allow. The line of demarcation between the old material and the reinforcement shows plainly in Fig. 30.

COMBINATION SLAVIANOFF AND BERNARDOS PROCESSES

The C. & C. Electric & Manufacturing Company, who recently took over the Garwood electric welder, market an apparatus which combines the Bernardos and Slavianoff processes. The carbon electrode is used to heat up the work to be welded and when this is accomplished, the operator pushes a button in the base of

the welding clamp which shifts the current from the carbon to the metallic electrode and this electrode is pressed against the work as fast as it melts.

An automatic series relay on the generator panel prevents the metallic contact made when the pencil is pressed against the work

FIG. 31.—Arc welder using combination graphite and metallic electrode and melt bar. (Courtesy C. & C. Electric & Mfg. Co.)

from causing a short circuit through the generator. In this process it is usual to hammer the weld while hot.

THE THOMSON PROCESS

"This process differs radically from all the others in *forcing through the metal to be heated electrically such volumes of current that its own resistance is sufficient to bring every molecule of the section traversed by the current to the desired temperature.*"[1] Current is taken from a lighting or power circuit, is stepped down to the required 3 or more volts and higher volume, and is passed through a secondary circuit in which the greatest resistance is offered by the pieces of the metal to be welded. The cross-section and unit resistivity are so proportioned to the flow of current that the resistance produces red or white heat at the

[1] Hermann Lemp, *The Engineering Magazine*, Aug., 1894.

point of welding. The hot metals are then forced together and the weld is made. The apparatus necessary are:

1. A generator of alternating current.

2. A step-down transformer, carried in the body of the welder.

3. Apparatus for regulating the current, and sometimes apparatus for automatically shutting off the current as soon as welding heat is reached.

4. Clamps for holding the metal to be welded and to transmit the current to it.

The Thomson process presents a number of decided advantages. Among them:

1. It is at present the best all-around welding machine for welding continuous runs of one weld, such as printers' chases.

2. The power used is claimed to give a 75 per cent. heat efficiency; the power is used only as long as needed, and is turned off as readily as the hot-flame welding burners.

3. The heating is rapid, even, entirely local, and is under control.

4. There is no excessive heating as with the electric arc; hence no excessive oxidation or decarbonizing of the metal.

5. The clamps hold the work in accurate alignment and furnish pressure enough to squeeze well the hot metal.

6. The workman is in no danger of injuring his eyes by excessive light, nor is the current at all dangerous. The operator works without dark glasses or protective apron and can hold the metal bars while the welding is going on.

The present limitations of the process seem to be:

1. Though it will weld odd or job work, it is practically limited to continuous welding of one article, known as *repeat welding*.

2. Though such metals as brass and cast iron can be welded on the Thomson machine, the company does not recommend it for such metals as have a marked melting point and which are not plastic below that point. High-carbon steel does not give an altogether satisfactory weld with this process.

3. The machine demands power at irregular intervals. For this reason station engineers may object to having a single machine of large size on their lines.

Apparatus and Current. The Generator.—Welding is now generally done with current from the city lighting circuit. Rarely are special dynamos used for supplying current to welding machines, as current suitable for welding purposes can now be found

most anywhere. This current is usually supplied by public service corporations. Thus a machine built for sizes of iron and steel not more than 1/3 inch square may be connected to the city alternating-current lighting wires at 104 volts. The following table gives specifications for specially designed welding dynamos:

TABLE 14.—GENERATORS SPECIALLY ADAPTED FOR ELECTRIC WELDING, 220 TO 3300 VOLTS

(Warren Electric Mfg. Co.)

K. W.	R. P. M.	Approx. weight	Price list	K. W. exciter	Exciter R. P. M.	Standard Pulley	
						D.	F.
22.5	900	3100	1250.00	1	1725	21½	4½
30	1200	3200	1300.00	1	1725	16	4½
50	900	4900	1700.00	1	1725	21½	7½
60	900	6500	1850.00	1½	1600	21½	10
60	720	8200	2200.90	1½	1600	27	9½
60	600	9100	2550.00	1½	1600	32	9½
75	720	9400	2550.00	2	1450	27	12½
75	600	10500	2800.00	2	1450	32	12½
90	720	10800	2800.00	2	1450	27	15
100	600	12000	3200.00	2	1450	32	15

In this process alternating current is invariably used, though there is no electrical reason why direct current should not be used. It is claimed for alternating current that its heating action is more uniform. As it flows mostly on the surface of the conductor,

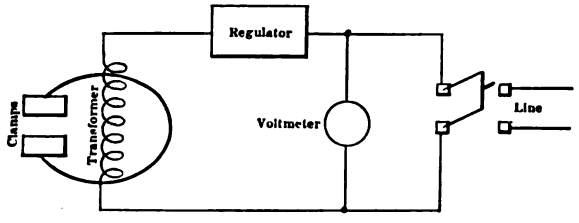


FIG. 32.—Diagram of Thomson electric welder.

its heating effect begins and is most intense on the surface. This heat is evenly conducted to the core of the welded pieces; thus the radiation and conductance are offset. The periodicity of the current may vary between 50 and 250. As low as 20 may be

used. Guarini[1] recommends 80 to 250 on welds of 4-inch square section, which, however, is larger than work ordinarily welded by electricity. The lower the periodicity, the less will be the skin effect, and hence the less the tendency for the current to crowd toward the outside of the parts to be welded. The Thomson machine is now designed for alternating current of 40 to 60 cycles.

Fig. 32 shows the Thomson apparatus diagramatically.

The Transformer.—Current from a lighting circuit of 54 or 104 volts was formerly used in what was called a direct welder. This welder had no transformer; it was used for small work only. The direct welder is now obsolete. All welders, whether for 104 or more volts, have transformers, as a current of 4 to 10 volts is the best and cheapest in the welder.

The transformer used is of the core type. It consists of a core of soft iron surrounded with the primary and secondary coils, the first of which introduces the primary current at relatively high voltage and low amperage, and the second of which leads off the current for the secondary or welding circuit at relatively low voltage and high amperage. The secondary coil is a solid copper casting encircling the core. In the larger machines, the heating effect of the current transformation is overcome by passing a steady current of oil over the transformer which is encased in a tight box. This oil is either air- or water-cooled.

Fig. 33 shows a machine with two transformers, one for heating and one for welding. The machine is described as follows:

"There are two separate transformers in the machine, on one of which is mounted a gun-metal platen, sliding on the right-hand or welding transformer. The left-hand contact, or electrode, is located between the contacts of the heating transformer and is adjustable for any required space between the electrodes of the two transformers by a screw at the left of the welder; the right-hand platen being moved to and from the left-hand contact by the pressure lever at the right. The cam levers, which hold the piece to be welded tightly on the electrodes, are fastened to the cast-iron bracket, and are adjustable to varying thicknesses of stock.

"The circuit in the transformers is opened and closed by two pole break-switches, which are furnished with the welder and should preferably be installed at the back of the machine; treadles, which are

[1] *Scientific American Supplement*, Nov. 5, 1904.

connected by chains to the break-switches, project under and at the front of the welder, and are operated by foot.

"One piece is laid on the terminals of the heating transformer in the direction of front to back of the welder, and is securely held by bringing forward the cam lever, the circuit is then closed by placing the left foot on the break-switch lever, and, while the piece is rapidly heating between the electrodes, the other piece is laid on the electrodes of the right-hand or welding transformer and tightly clamped by the other cam lever. The foot is then released from the break-switch treadle of

FIG. 33.—Thomson double transformer welder, for dash and fender frames. The clamping device can be modified to take other right angle pieces.

the heating transformer and transferred to that of the welding transformer, when the second piece, immediately coming to a welding heat, is forced against the heated section of the first piece by the pressure lever, upsetting against and fusing with it. The foot is then removed from the break-switch treadle, and the cam levers are thrown back, releasing the welded pieces."

The transformer is the heaviest part of the welding machine. So it is placed in the body of the welder frame, underneath the clamping table. It thus gives stability to the machine. Fig. 33

shows the transformers in plain sight. In Fig. 38 the transformer is covered from view in the body.

TABLE 15.—TYPICAL THOMSON WELDERS

Weight in pounds	Floor space		Maximum watts	Maximum area □"		H. P. to dynamo
	Length	Width		Iron	Copper	
125	13"	12"	1,000	0.05	.....	2
150	15"	12"	2,000	0.10	.....	4
140	13"	14"	2,000	.....	0.0209	4
525	27"	15"	5,000	0.30	0.110	9
800	28"	18"	7,000	0.25	.....	12
900	32"	20"	10,000	0.60	0.20	17
2,200	54"	30"	20,000	1.23	0.40	35
2,400	70"	30"	20,000	1.23	0.40	35
7,000	90"	36"	40,000	3	0.79	80

Regulating Apparatus.—Regulating apparatus for the dynamo is assembled on the switch-board switches, fuse blocks, rheostat

FIG. 34.—Thomson type reactive coil, for controlling current in welding machine.

and potential indicator. The welder carries its own break-switch and reactive coil.

The reactive coil (Fig. 34) is to control the current at the welder when a great variety of sizes is to be welded. It consists

of an iron base, a copper hood, a switch, and two laminated iron cores; the smaller core carries the copper hood and partly rotates within the larger core which has four distinct coils wound on it. These coils can be connected either in series, series multiple, or multiple, by means of the switch in the base, which is operated by the handle projecting through side of base. The hood is moved over the winding by a worm gear, which is operated by the wheel at the front.

When the switch handle is in position No. 1 and the hood farthest away from the winding, the minimum current is obtained.

When the switch handle is in position No. 2 and the hood farthest away from the winding, the mean current is obtained.

When the switch handle is in position No. 3. and the hood over the winding, the maximum current is obtained.

The reactive coil also regulates the potential for metals like iron, which are good conductors when cold and become more resistant when hot.

A fairly efficient makeshift rheostat was formerly made of a barrel of water into which a metal disk was lowered and raised. The disk served as one pole and the bottom of the barrel as the other pole. The sides of the barrel were insulated.

Regarding the high peak loads caused by a large Thomson machine *The Electrical Times*[1] has this to say:

"Central station engineers have hitherto been somewhat chary in connecting electric welders of large size to their mains on account of the fluctuating nature of the load, although there are numerous instances of small welders being so used. A very interesting installation has recently been completed in London by the Electric Welding Company, Limited, in which a welder of 90 k.w. capacity is worked off a single-phase power supply at 400 volts. In order to prevent undue fluctuations of voltage on the mains, a special substitutional resistance is installed, built in three sections, each controlled by a switch, so that one or more sections can be put in circuit according to the size of the work being welded. A large liquid resistance is also employed to prevent an undue rush of current, when the primary circuit of the welding transformer is closed, the plates being raised and lowered by a small motor through suitable gearing. The controlling switch of the welder is so arranged that when put in the 'on' position it starts the plate-lowering gear, thus gradually cutting out the starting resistance, and *vice versa*. This plant is in continuous operation, and no inconvenience to other power users in the neighborhood has been reported. Another

[1] September 5, 1907.

TABLE 16.—REPRESENTATIVE THOMSON WELDERS

No.	Type of welder	Kind of work	Round		Flat		Crescent		Channel		If circle min. dia.		Aprox. weight lbs.		Max. watts cap.	No.
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.			Net	Gross		
1	1 A A Hand automatic	Copper wire	No. 23	No. 15	.....	.....	....	....	....	....	No. 23 No. 15	1″ 2″	92	120	1,500	1
2	2 A Hand automatic	Iron and steel wire	No. 16	No. 8	.....	.....	....	....	....	....	No. 16 No. 8	1½″ 6″	150	200	3,000	2
3	2 A A Hand automatic	Copper wire	No. 16	No. 6	.....	.....	....	....	....	....	No. 16 No. 6	1″ 6″	140	190	3,000	3
4	2 A Automatic	Iron and steel wire hoops.	No. 14	No. 11	.....	.....	....	....	....	....	No. 14 No. 11	1½″ 2″	150	200	3,000	4
5	3 A Automatic	Iron and steel wire hoops.	No. 10	No. 8	.....	.....	....	....	....	....	No. 10 No. 8	2″ 2½″	300	380	4,500	5
6	5 A Hand automatic	Iron and steel wire.	No. 8	⅝″	.....	.....	....	....	....	....	No. 8 ¼″	2½″ 6″	525	665	7,500	6
7	5 A Standard	Iron and steel	No. 8	⅜″	⅜″x 1/16″	1″x⅛″	⅜″	¾″	....	½″	No. 8 ¾″	2″ 6″	525	665	7,500	7
8	5 A A Hand automatic	Copper wire	No. 6	5/16″	3/16″x 3/32″	⅜″x 3/32″	....	....	....	....	No. 6 5/16″	3″ 8″	550	700	7,500	8
9	7 A Automatic	Iron and steel square or rectangular frames.	No. 8	½″	.....	.....	....	....	....	....	No. 8 ½″	2″ 6″	800	900	6,000	9
10	10 A Cortland	Right angles and carriage rails.	½″	½″	.....	1¼″x⅜″	....	....	....	....	.....	....	900	1,100	15,000	10
11	10 A Standard	Iron and steel	½″	½″	½″x⅛″	1¼″x¼″ 2″x 1/16″	⅜″	1¼″	½″	1″	½″ ½″	2″ 10″	900	1,100	15,000	11
12	10 A Double transformer	Right angles and dash and fender frames.	½″	⅝″	.....	⅜″x¼″	....	....	....	....	.....	....	900	1,100	10,000	12
13	20 A Pipe	Extra heavy iron and steel pipe.	¾″	2″	.....	2½″x⅜″	Solid rounds and squares can also be welded from ½ to 1¼ sq. in.				.....	....	2,600	3,000	30,000	13
14	20 A Standard, quick operating clamp.	Iron and steel flat stock.	½″	¾″	¾″x 1/16″	2¾″x¼″ 2¾″x 1/16″	1″	2″	⅜″	1¼″	½″ ¾″	5″ 8″	2,500	2,900	30,000	14
15	20 A Automobile rims	Iron and steel flats.	.....	.....	1″x¼″	4½″x 3/16″	Some simple forms in profile can also be welded.				1″x¼″ 4½″x 3/16″	20″ 24″	2,500	2,900	30,000	15

TABLE 16.—REPRESENTATIVE THOMSON WELDERS.—*Continued*

No.	Type of welder	Kind of work	Round		Flat		Crescent		Channel		If circle min. dia.	Aprox. weight lbs.		Max. watts cap	No.
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		Net	Gross		
16	20 A Vertical oblique, fast operating clamp	Iron and steel axles and tires.	$\frac{1}{8}$″	$1\frac{1}{2}$″	$1\frac{1}{2}$″×$\frac{1}{4}$″	3″×$\frac{1}{16}$″	1″	2″	$\frac{1}{8}$″	2″	$\frac{1}{4}$″ 5″ $1\frac{1}{4}$″ 25″	2,700	3,100	30,000	16
17	20 A Vertical screw medium fast operating clamp.	Iron and steel axles, tires, channels and disks.	$\frac{1}{8}$″	$1\frac{1}{2}$″	$1\frac{1}{2}$″×$\frac{1}{4}$″	$2\frac{1}{2}$″×$\frac{1}{16}$″ 2″×$\frac{1}{16}$″	1″	2″	$\frac{1}{8}$″	2″	$\frac{1}{4}$″ 5″ $1\frac{1}{4}$″ 25″	2,800	3,200	30,000	17
18	20 A Pipe.....	Steel tubing.....	$\frac{1}{8}$″o.d.	$1\frac{1}{2}$″o.d.	$1\frac{1}{2}$″×$\frac{1}{4}$″	$2\frac{1}{2}$″×$\frac{1}{8}$″	Solid rounds and squares can also be welded up to $1\frac{1}{2}$ sq. in.				....	2,700	3,100	30,000	18
19	40 A Horizontal.....	Iron and steel axles and tires.	$\frac{1}{4}$″	2″	$1\frac{1}{2}$″×$\frac{1}{8}$″	4″×$\frac{1}{4}$″	2″	3″	$\frac{1}{8}$″	2″	$\frac{1}{4}$″ 5″ 2″ 40″	7,200	7,800	60,000	19
20	40 A Pipe.....	Extra heavy iron and steel pipe.	1″	3″	.....	$3\frac{1}{2}$″×$\frac{1}{4}$″	Solid rounds and squares can also be welded up to 3 sq. in.				....	7,200	7,800	60,000	20
21	40 A Rod.....	Iron and steel axles, etc.	$\frac{1}{4}$″	2″	$1\frac{1}{2}$″×$\frac{1}{8}$″	4″×$\frac{1}{4}$″	.....	.....	.....	.....	$\frac{1}{4}$″ 5″ 2″ 40″	7,200	7,800	60,000	21
22	40 A Automobile rims..	Iron and steel flats.	.....	.....	2″×$\frac{1}{4}$″	$4\frac{1}{2}$″×$\frac{1}{16}$″	Some simple forms in profile can also be welded.				1″×$\frac{1}{4}$″20″ $4\frac{1}{2}$″×$\frac{1}{16}$″ 28″	7,000	7,600	60,000	22

Copper wire B. & S. gauge. Iron and steel wire W. & M. gauge.

Right angles 2/3 of sizes of rounds and flats can be welded on Nos. 16 and 17 welders, also disks up to 2 1/2×3/8 on No. 16 and 4×1/4 on No. 17 welders, not less than 10 inches in diameter.

Squares and ovals can be welded in all welders equal in sections to rounds and flats, except No. 10 welder in which the limit is 3/4×7/16 oval.

When only the maximum sizes of stocks are to be welded no reactive coil is required with any welder, but when minimum sizes, or all sizes within the capacity of the machine are to be welded a reactive coil is required; type 2-EE reactive coil with welders up to and including 7-A, 4-EE with 10-A welders, 10-EE with 20-A welders, and 20-EE with 40-A welders.

WEIGHT OF REACTIVE COILS

	Approximate net and gross weight; lbs.	
Type 2 EE, Reactive Coil,	120	175
Type 4 EE, Reactive Coil,	190	265
Type 10 EE, Reactive Coil,	400	500
Type 20 EE, Reactive Coil,	600	700

An *alternating* current is absolutely required; a direct current cannot be used. The welders are built for 50 cycles, but up to and including 5A they are sometimes used on a circuit as high as 125 cycles, but never lower than 50 cycles. Welders larger than 5A can be used to the best advantage on circuits between 40 and 60 cycles.

Any voltage from 100 to 350 can be used for the smaller welders, and from 200 to 350 for the larger; but it must be constant and not drop during the time of heating the stock

welder of smaller size has also been connected to this circuit. In this case a special economy coil is used as a regulating device.

"To facilitate the working of electric welding machines on polyphase circuits, Professor Elihu Thomson has recently patented a method of winding the transformers to prevent unbalancing the phases. This will doubtless lead to considerable development in the near future, seeing that the power companies' supply mains are available in most manufacturing centers."

On account of the type of welds it handles, the Thomson welder is often made automatic. Suppose a welder is being fed links of a chain to be welded. If the welder will put through each weld automatically, a uniform product will be secured and

A *B*

FIG. 35.—Two types of Thomson automatic break switches.

labor, time, and current will be saved. The automatic shut-off (Fig. 35) is a switch in the primary circuit which is thrown open as soon as the clamps move together on the yielding metal. The current is not used any longer than is necessary to heat the joint.

The break-switch shown in Fig. 35 is used with the larger welders, heavy currents being employed, and should be installed at the back of the welder. The switch is out of reach and is operated with the foot by the lever; this lever should run under the base of the welder, the end projecting at the front of the welder at a convenient place for the operator.

The Clamps.—The clamps vary in design in different types of machines. Figs. 33 and 36 show clamps for various work.

They are generally of heavy copper, to allow for the passage of the large volume of current. The clamps are not rigid in a welding machine, but are pivoted or mounted on a straight sliding groove, and are made to move toward each other by a lever, wheel-and-screw, or by hydraulic pressure. Recently the hydraulic pressure has been made automatic, so that the machine will throw on its own current as soon as the pieces to be welded are clamped, will squeeze the pieces together at the temperature of plasticity, and will throw off the current at the same time.

Where heavy bars are to be welded, and a good electrical

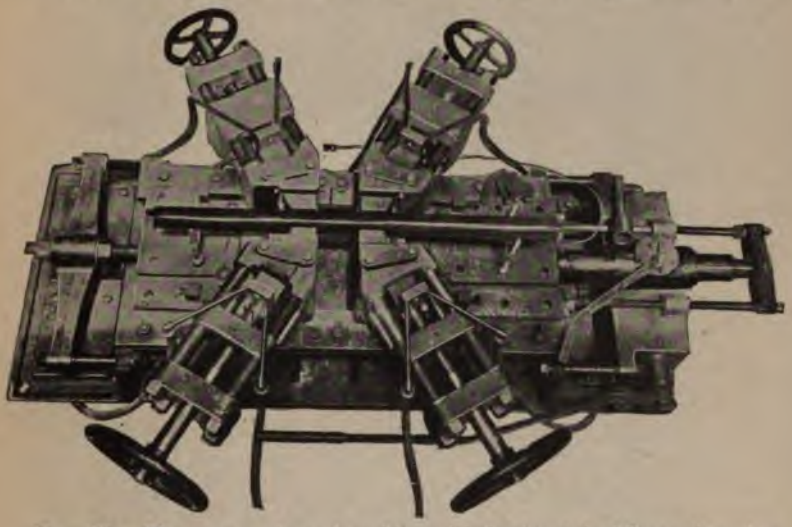


FIG. 36.—Thomson universal welder with horizontal oblique clamping device and hydraulic jack for pipe straight-away and miscellaneous work.

contact is needed at the clamps, the clamps are operated hydraulically.

As will be guessed, the clamps are liable to get very hot, especially on continuous runs of heavy work. As heat affects the conductivity of the clamps, they are often water-cooled.

Some of the automatic machines are equipped with swages working between the electrodes. These swages are brought together on the weld immediately after the hot metal is upset. They compress the upset or bur and give the weld any desired shape. Besides which, their pressure amounts to working of the metal and makes the weld much stronger.

Practice.—The operation of the Thomson electric welder is very simple, calling for much less skill than the hot-flame processes. For each weld the current is first calculated for the size of the piece to be welded and the kind of metal in the piece. Tables of current value, cross-section, and time have been worked out for iron, steel, brass, and copper. The machine being adjusted

FIG. 37.—Thomson special machine for welding hubs and spokes in agricultural wheels, approximate weight 7,500 pounds.

for stock welds will handle them rapidly without readjustment, much the same as a printing press will run off many impressions of the same form.

The operator places his pieces in the clamps, closes the clamps, and advances the clamps toward each other until the two pieces touch closely. He turns on the current and as soon as the pieces

become plastic or semi-molten at the point of contact he turns off the current and squeezes the clamps toward each other until the pieces become welded and upset at the contact.

Fig. 38 shows a semi-automatic machine. The copper contacts, carrying the clamping device, move to and from each other: the left is moved by a screw to get the required opening between clamps; the right is held apart by the lever. The wire is inserted and tightly held in the clamps, the side lever raised, the

FIG. 38.—Thomson type 5AA electric welder for copper wire from No. 6 to 14 in. Time in heating from 2 to 6 seconds. 7,500-watt alternating current, not lower than 50 cycles, from 100 to 350 volts.

circuit closed through the hand-automatic break-switch in the base of the welder, and the pieces, instantly heating at the joint, are forced together by the weights; the circuit being automatically opened by the adjustable cut-out device.

In making the joint, the metal is upset, the extent of which depends largely upon the weights and the adjustment of the cut-out device.

When full range of sizes is to be welded or when the smaller

ferent sizes, shapes, and different metals he will have to use his gray matter continually in the regulation of the current, clamps, and the amount of upset and time of cooling before removal from the clamps. Many firms use this welder for job welding, though it is not specially adapted to job work.

A number of precautions are necessary in the different steps of welding. In the first place, the metal should be very clean, both at the clamps and at the points of contact where the weld is to be made. The metal can be cleaned in a number of ways. If the metal pieces are at all oily they are first dipped in a bucket of lye and then in a bucket of water. If the pieces have any petroleum oil on them, the lye will not clean them, and they must first be wiped down with waste. Sand-blasting and tapping will remove the scale. Any remaining dirt can be forced out into the upset.

Then the clamps must be set lightly on the pieces, and the contact surfaces must be as large as possible so that there will be good electric conductance. If the contact at the clamps is imperfect the clamps will become heated.

The distance between the clamps varies with the diameter of the metal pieces and also with the kind of metal. In a general way, the distance between clamps is equal to twice the diameter, with iron; is three times as great as the diameter, with brass; and four times, with copper. This difference, of course, is caused by the higher conductivity of copper, which requires the immense volume of 60,000 amperes per square inch of metal.

Some metals are best heated rapidly. Steel, rolled copper, and like metals, which are easily ruined by heat, must be handled with care. They must be heated as quickly as possible; and they must not be overheated, or they will lose their structure. The act of forcing the hot ends together and squeezing the metal helps to maintain the structure and prevent crystallization. Such metals should be worked or hammered while cooling. In welding tool steel the ends are forced together until the overheated metal is all forced out of the joint into the upset. Of course, any scale or dirt is also forced out. When copper wire is welded, it should be upset and then drawn down to the proper gauge. In this way joints of nearly equal strength can be made. While quick heating is a good thing, the joint can easily be heated so rapidly that it will be overheated. No metal can stand overheating.

Contrary to common conception, the welding heat is *not* caused by imperfect contact at the joint. The pieces should fit as

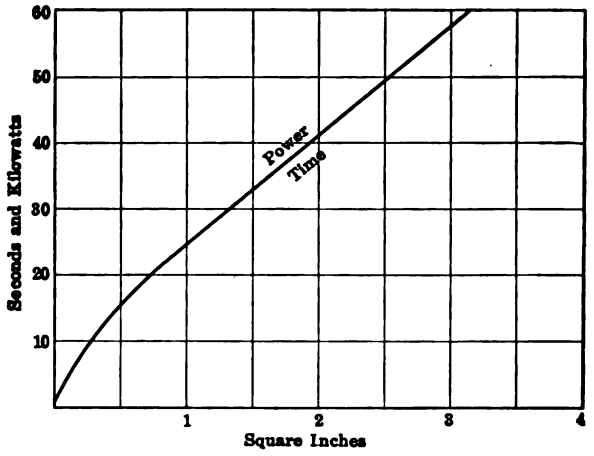


FIG. 39.—Power and time required to butt-weld iron rod. Thomson process.

closely as possible before welding. A poor contact will simply delay the heating.

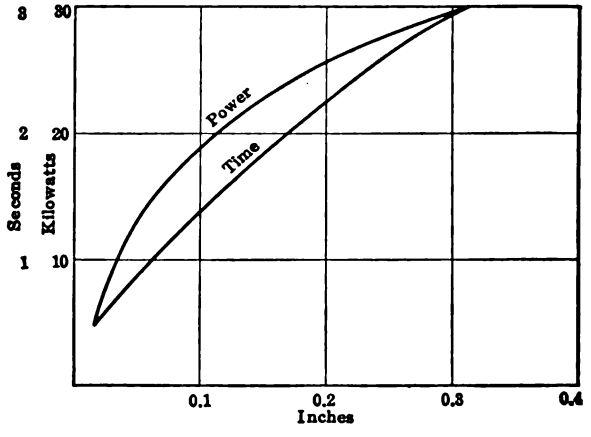


FIG. 40.—Power and time required to spot-weld steel plates. Thomson process.

Rapid welding calls for larger dynamo and welder at greater cost, but the increased efficiency will more than pay for the out-

lay. Seven-horsepower minutes is given as the approximate figure for bringing one cubic inch of iron to welding heat.[1] If the metal clamps conduct the heat away rapidly, from 10- to 15-horsepower minutes are required.

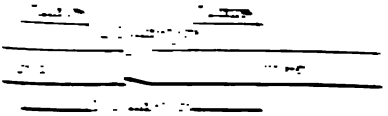
All of the metals of commerce have been welded by this process, both to themselves and to each other. Those metals which are most plastic at welding heat and which have the widest range of plasticity will weld the most readily. Metals which oxidize can be fluxed with borax, sand, sal ammoniac, zinc chlorid, etc., but in most cases fluxing is not necessary. The oxid at the contact can be forced out into the upset. Brass is generally fluxed.

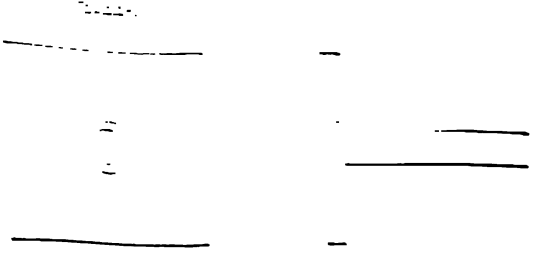
Prof. Thomas has in his possession a metal bar of 3/8-inch diameter which is made of nine different metals welded together. However, the Thomson Company does not recommend its machine for cast iron or similar metals of well-defined melting point and which are brittle up to that melting point. Cast-iron pieces can be melted in the welder and their ends stuck together. It is necessary to build up a clay or asbestos form around the joint so that the metal will not run away when it melts. Brass must be treated in the same way. On cooling it will become brittle and crystalline. This is a trouble, however, which is common to all the welding processes. If you are welding a troublesome metal you may as well expect doubtful results. The welding of copper by this process has been a disappointment to some, while others claim complete success for their copper welds. It is evident that the difference between good and bad welds in many instances is due to the skill employed.

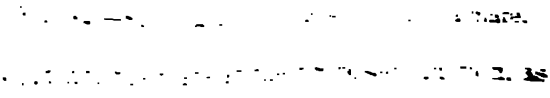
Adaptability.—In the last decade the Thomson or similar machines have forced their way into many of the metal trades. In factories where stock welds are made, this process is invaluable. There is a long list of implements that are now welded in the process of making. Those industries which are most benefited are the wagon and carriage, bicycle, tools, wire, chain, pipe and pipe bending, and miscellaneous, which includes angle welding, typewriters, printers' chases, wire fence, tool steel to steel, springs, bands and rings, umbrella rods, etc.

Occasionally the joining of two different kinds of metals or of metals of unequal sizes will call forth the ingenuity of the workman. Copper and brass are frequently welded to iron. When metals of unequal electrical conductivity are welded, the clamps

[1] *The Engineering Magazine*, Hermann Lemp, Aug., 1894.







welded by the

pedals, crank hangers, mud-guards, etc., are welded. Automobile making is equally dependent on electric welding.

Iron or brass pipe is butt-welded and also heated preparatory to bending. In England wrought-iron pipes are flanged very successfully.

A number of firms weld printers' chases by this method. The bars are held in the hands of the operator, are butt-welded, and then right-angled on a frame. The burr or upset is trimmed off on a metal saw and ground even on a wheel.

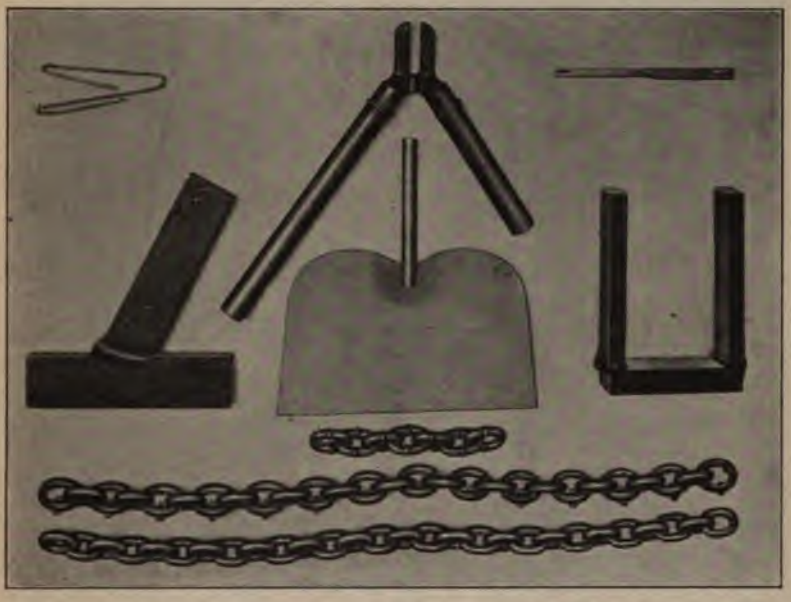


FIG. 43.—Thomson specimens. Type bars, steel to brass; angle weld; bicycle fork; hoe; corner angle weld; chain, two welds, chain showing fin after welding; chain welded and fin removed.

Chain is being welded by the electrical process; as fast as ten links a minute can be turned out on the smallest sizes. In this case some of the current, approximately 10 to 30 per cent.,[1] travels around the ring instead of over the joint. This loss of current is expensive and stands in the way of the general adoption of this process to chain welding. But it is also claimed that this short-circuiting of part of the current causes the ring to heat sufficiently to bend with ease when the ends of the link are closed.

[1] *Iron Age*, W. S. Gorton, July 27, 1905.

It is claimed that a bar magnet thrust through the link to be welded will largely prevent the current from traveling around the link.

In the welding of hoops and rings this same objection appears. The loss of current is much less for rings of large diameter and small gauge, and can be further reduced by placing the clamps closer than is the custom.

Electric welding is much used in the manufacture of projec-

FIG. 44.—Thomson specimens. Tee weld in pipe; ferrule; wire handles; bicycle head; sheaves; band saw steel automobile rim; pipe; tee weld; wire mesh.

tiles and the parts of machine guns. A special high-carbon head can be welded on to a soft-steel projectile cartridge.

Brass heads are joined to steel shanks for use in switchboards.

Garden rakes that were once made of cast iron are now made much lighter and stronger by putting the teeth on a bar. Both teeth and bar are of wrought iron or steel, and are lighter and much stronger than the old cast rake.

Wheelbarrows are made of welded-steel wheels and frames.

In the wheels, the rim is welded into a hoop, and the spokes are welded both to the rim and to the hub.

The heads of cap screws are now successfully welded onto the shanks. This allows the manufacturer to cut his thread in the hard outer layer of steel. Formerly the screw was cut from a billet of the diameter of the head. The head was harder than

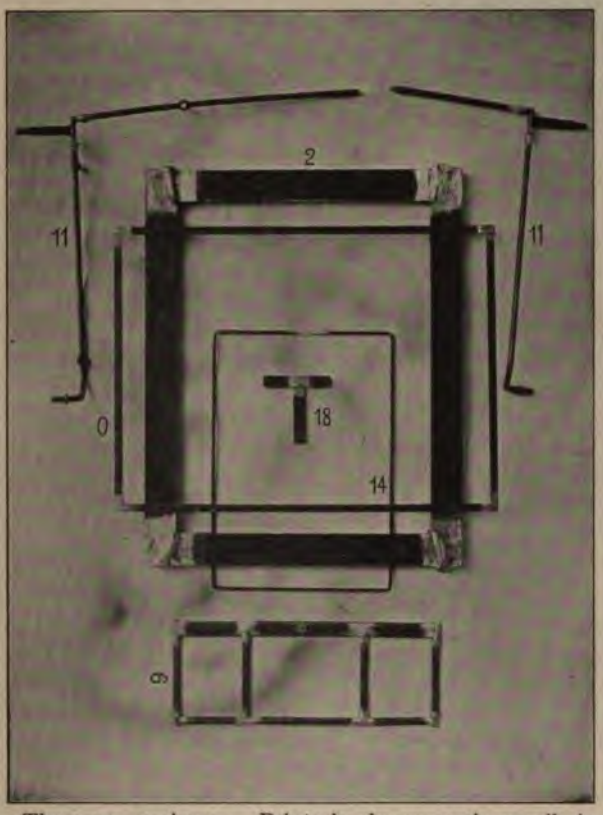


FIG. 45.—Thomson specimens. Printer's chase; carriage rail; bag frame flat; T weld; bag frame on edge; dash frame.

the thread which was turned out of the softer metal near the core. It is claimed that the increased strength of the thread and the decreased cost of turning down the shank offset the cost of welding.

Rail welding was first suggested by Thomson and practised with one of his machines. On account of the importance of elec-

tric rail welding and the special apparatus needed, the process will be described in detail.

The most recent application of the Thomson process is to the welding of sheets of metal. Two sheets of steel are lapped and welded at regular intervals in points similar to riveting. "The method consists in bringing two pointed electrodes against the two sheets, or prepared sheets with slight projections, by indenting or punching. The current flows through these projections which are pressed down flat on the sheet, effecting the weld. This method is used in interior furnishings of steel railway cars, passenger coaches, steel furniture, sheet-metal ware, etc."[1]

FIG. 46.—Thomson specimen. Automobile clincher rim.

Locomotive Flue Welder.—The Warren Electric Manufacturing Company has furnished the following description of their flue welder, which is especially adapted to the work:

"The flue welder (Fig. 47) operates from an alternating source of electromotive force, and steps the voltage from any convenient line voltage down to from 5 to 10 volts on the weld by means of a transformer enclosed in the body of the welder. The secondary leads from the transformer are connected to two copper contact shoes, which hold the ends of the flues to be welded. These contact shoes have a copper top clamping piece, operated by cam levers, which clamp the flue very securely. The top and bottom members of this clamp are cooled by means of running water. On of these pipe clamps which holds the shorter end of the flue is operated longitudinally by means of a lever, so as to bring the ends of the flues into contact under heavy pressure. One of the foot treadles operates a switch in the primary circuit for controlling the heating of the joint. The second treadle

[1] Special information furnished by the company.

operates a die which is brought up so as to surround the joint at the time at which compression take place and prevent an external upset around the pipe at the joint. This die is also water-cooled.

"Owing to the circular form of the pipe, the compression at the joint produces a pressure on the interior portion of the pipe, which increases the density of the metal. This increased density resists the tendency to expand internally, as the metal naturally expands in the direction of the least resistance. It has been found experimentally that there is no tendency whatever to an upset on the inside of the pipe. When the

FIG. 47.—Locomotive flue welder.

flues are welded without the clamp die, the free flow of the metal is all outward, which produces an exterior upset only.

"The operation of the welder is as follows:

"The two ends of the flue are clamped in place, and then brought into contact by means of the horizontal hand lever. The current is thrown on, and the metal at the joint gradually brought up to welding heat. Immediately upon reaching the welding heat, the current is thrown off, and the dies for controlling the form of the weld are brought up into contact with the work by means of the second treadle. A further movement of the horizontal lever is then made so as to produce

a very heavy compression of the joint inside of the die. After compression the die is then released, and also the top clamps, so as to relieve the pipe of strains during the cooling of the joint.

"The advantage of this form of welder is a practically smooth joint on the outside of the pipe, which permits the flues after welding to be placed in the end sheets of the boiler without reducing the upset usually met with on butt-welds made by the electrical process. In welding flues electrically, this exterior upset is accompanied by an expansion of the pipe at the joint, so as to produce an annular groove inside the pipe, which is objectionable in boiler flues on account of the accumulation of scale therein. This annular groove is of course entirely eliminated in the flues as welded by this machine."

Rail Welding by the Thomson Process.—The most important single application of the Thomson process has been to the welding of street-car rails. Before 1892, all rail welding was done by the *cast-welding process.* Cast-welding is briefly as follows:

It is desired to save a piece of track from scrapping, that is

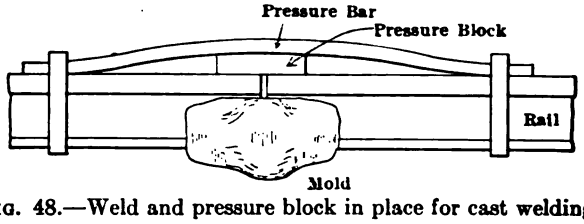


FIG. 48.—Weld and pressure block in place for cast welding.

weak at the joints, and whose rail heads have been considerably worn. The cast-welder machine consists of two cars. The first car contains the sand blast which cleans all dirt from the rail joint. A cast-iron mold is then clamped on to the joint, and the ends of the rail heads are pressed down by a block which prevents them from springing when the joint is cast (see Fig. 48). The second car is now moved over the joint mold. This second car contains the melting cupola—a small, coke-fed blast furnace which melts down a mixture of charcoal iron and assorted scrap until it is at a high temperature. This very hot iron is run into the mold and forms a cast-weld around the heads of the rails. Examination of this joint shows that the cast iron of the joint and the steel of the rail have amalgamated. The cast-weld is still being used, though it has strong opponents. As many as 200 cast-welds can be made per day.

Los Angeles there are several hundred miles of cast-
ed track that are being displaced as unsatisfactory. Only
oint in ten was found to have amalgamated at the so-called
The result was a loss of electrical conductivity of from
75 per cent. The cost per cast-welded joint was given as
ıly $7.00 as against $5.00 to $6.00 for the thermit joints
ı are displacing them. The breakage was said to be about
cent. per annum, and track that was welded in cold
her broke the least. "Sun snakes" were a common occur-
, and were prevented by building the paving close to the
No open rail track can be welded, as it will warp and
e.

cently the electric roads have begun to adopt the electrically
ed rail and also the thermit-welded rail. Welded rails are a
improvement over those joined by fish-plates and bonded
copper wire, for conducting the current:

The conductivity of the weld is as good or better than the
section of rail. There is no bonding to come loose or leak
stolen.

The rail will last much longer.

Welded track is smoother riding.

ils running through city streets are well embedded in the
t. If the street paving is not a good conductor of heat and
xtremes of summer and winter temperature are not too great,
long sections of track can be welded into one piece without
of pulling loose at the ends or at any of the joints. A section
00 feet has been solidly joined at Holyoke, Mass. It is cal-
ed that the coefficient of expansion of steel in such a climate
l cause a stress of about 16,000 pounds to the inch, while
ensile strength of the rail would run well over 40,000 pounds.
ion of the pavement against the rail and inertia of the rail
nt dragging, and the expansion and contraction are taken
the elasticity of the rail. Rails welded with thermit or by
icity are less liable to crack or pull apart at the weld than
ast-welded rails.

e Thomson process was the first process of welding applied
e production of continuous rails on electric railway tracks,
vas introduced by the Johnson Company in 1892.

1897, the Lorain Steel Company, successors to the Johnson
pany, improved the process and placed it actively on the
et. Since that time it has been made use of in almost all

the large cities of the United States, and the company found it necessary to double its equipment for this kind of work.

The joint consists of two bars welded to the web of the rail, one on each side. Three welds are made between the bars and the rail, one directly over the ends of the two rails and at each end of the bars. The central weld is made first. In cooling, the contraction of the bars draws the abutting rails together so that no opening remains across the head of the rail.

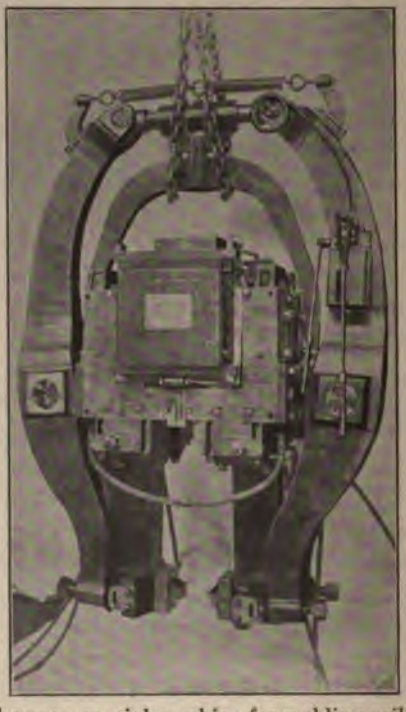


FIG. 49.—Thomson special machine for welding rails in streets.

The apparatus is mounted on four trolley cars, propelled by their own motors. The first car carries a sand-blast apparatus for cleaning the rails and bars. The welder is suspended from a crane projecting from the front of the second car (see Fig. 49). The welder itself consists of a "step-down transformer for supplying current for heating the weld, and hydraulic pressure apparatus for supplying a heavy pressure to the portions to be welded." Suitable mechanism is carried within the car for raising and

lowering the welder and to swing it from side to side to engage either rail. Coupled to the welder car, the third car carries rotary transformer and regulating apparatus for changing the direct current from the trolley to alternating current. A switchboard with instruments, etc., is also carried in this car.

The fourth car carries two grinder carriages, one suspended over each rail, to smooth down any inequalities that may exist on the head of the rail after the joint has been welded and to produce a true running surface.

The process has been successfully applied to all kinds of rail, both girder and T-rails. Also to the welding of the "third" or conductor rail on elevated and surface lines.

The process particularly commends itself for use in crowded city streets on account of its harmlessness, as it is not affected by dampness and there is no danger of explosions, etc., due to sudden rain storms. The apparatus is practically noiseless in its operation.

An interesting application was the welding of the T-rail on the surface track on the north and south roadways of the Brooklyn Bridge in 1906.

The cost of the equipment makes it more desirable for a railway company to have the welding done for them than to do it themselves.

The apparatus is also made use of for welding heavy copper cables to the rails, either for overhead return or around special work. As the conductivity of the welded joint is greater than the rail, a most perfect system of bonding is thus afforded at the same time with the elimination of the joints.

From ten to twenty welds are made per day by this machine. The breakage is said to run less than 5 per cent., and often not higher than 1 per cent. The machines are leased, not sold, and the cost must accordingly be figured on the rental, power, and labor in calculating the cost per joint.

Electric Resistance Heater.—Besides its use as a welder, the machine may be used as a preheater of metals to be brazed or bent. It will sometimes be preferable to braze or solder a joint, when the two metals cannot be allowed to lose their shape or have any of their substance pressed into an upset: the welder can then be used as a preheater. The current would be regulated to bring the metals to a slightly lower-than-welding heat and keep them at this heat. In brazing brass, this is the best-

known method of preheating, because a torch preheater always burns out some of the zinc in the brass and oxidizes the copper.

The Thomson welder may be used to anneal spots in armor plate. This is done by connecting the positive to the armor plate and pressing the negative clamp against the spot to be annealed.

Spot Welding.—The great field for electric welding is in sheet metal work where the spot-welding process is employed. The spot welder (Fig. 50) is a much simpler machine than the original welder. Its distinctive feature is the two arms, one of which is actuated by hydraulic pressure. The work to be welded, for instance two strips of metal to be riveted or welded in spots, is placed on the contact point of the lower arm; the upper arm is thrown into action by the treadle and as it closes on the work and presses it against the lower contact, the current flows through and welds the metal strips.

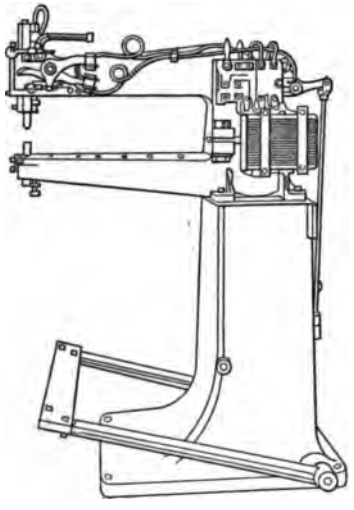


FIG. 50.—Thomson spot welder.

It requires a very heavy machine, both in its electrical and mechanical features; heavy hydraulic power is required to force the parts together at the junction. The welders are, however, self-contained, carrying all the features required to clamp, heat and press up the stock. As much as 175 or 200 kw. is employed during the minute or fraction of a minute that the weld is being effected.

The field for spot welding is probably as large, if not larger, than that of butt welding. Sheet metal requiring to be riveted, is rapidly displacing wood in the manufacture of many articles. It is believed that spot-welded sheet metal will eventually displace wood for interior finishing in all-steel cars, such as doors and furniture. It is also possible that all-steel structures, such as bridges, buildings, etc., will be electric welded instead of riveted.

Armor plate is annealed between the secondary terminal electrodes, the transformer being suspended over the plate, and the

size of the spot annealed is determined by the distance between the two electrodes.

The field of the Thomson welder is constantly widening. Figs. 51 and 52 show recent models which indicate how incandescent welding is adapting itself to miscellaneous manufactured products.

Fig. 51 shows an automatic machine for welding sheave pulleys.

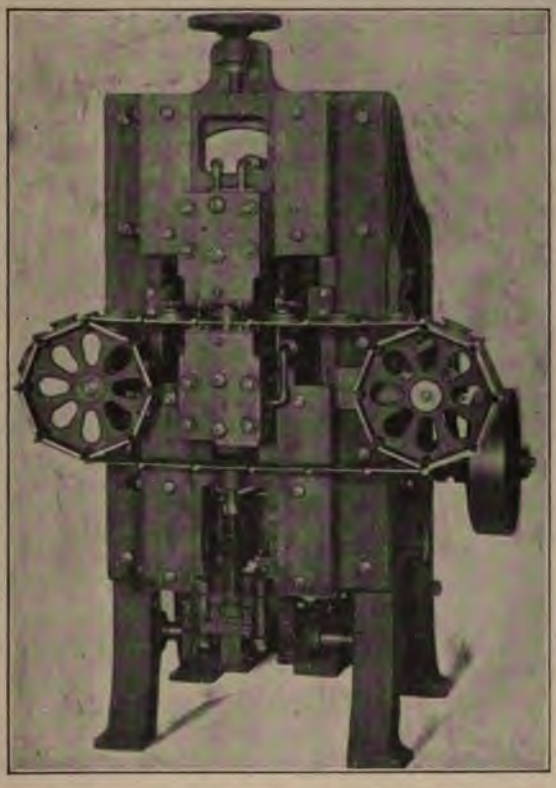


FIG. 51.—Sheave pulley spot-welding machine.

These pulleys are assembled from two pieces punched from a steel disk. At the same time bosses are punched on one side, through which the union is effected. These bosses show in the pulleys on the traveling belt to the right of the welder; those pulleys to the left of the welder have been welded and it will be noticed that the space between the two halves is closed. Ball bearings are used in these pulleys in some instances, and they are installed

in sheet steel metal housings, which are themselves electrically welded. So there is not a rivet in the whole fixture. An attendant has only to place the two halves of the pulley on the traveling belt.

Fig. 52 shows an automatic welder which makes wire fence and wire mesh for concrete reinforcing. The wire is fed in reels. Any number of strands up to twenty-two, any distance apart, can be run over the curved rolls and rack, properly spaced. These strand wires pass up the machine and a stay wire from a reel is

Fig. 52.—Automatic wire fence welder.

carried through the wire-straightener at the left across the machine, automatically cut off, and placed by the fingers, eleven of which are shown, across and against the strand wires at determined spaces. These fingers then withdraw and an electrode comes against the crossed wires and welds them, at the same time turning over the outside ends of the stay wire and welding it against the outside strand wires. It requires a number of transformers, sometimes two welds being made in one transformer, and sometimes only one weld. There is not much room to place these transformers and they are usually staggered for that

reason. There is an automatic current cut-off device at the rear of the machine, and the wire mesh is rolled up on a drum at the back. This machine is probably the only entirely automatic welding machine ever built.

Tests.—In general, tests of electric welds show that from 75 to 95 per cent. of the original strength of the metal is reached. In cases where the upset is not cut off, the strength can be increased above 100 per cent. Welds of low-carbon steel and low sulphur-and-silicon iron, if well made and worked or drawn after working, will approximate 100 per cent. in strength.

It is sometimes asked if the electric current does not damage the metal. Electric welding is no more harmful to the metal than any other process. In fact, the control of the heat is so exact and overheating and reheating so seldom happen, that electric welds run uniformly high in tensile and elastic strength. A "burned" weld seldom occurs—the oxid at the joint is forced out into the upset and ground off. It may be emphatically stated that the electric-resistance welds are the best yet made. As an instance, such a misused and overstrained utensil as a printers' chase seldom gives at the weld.

Sir Frederick Bramwell[1] states that 1 1/8-inch round bars can be welded in 2 1/4 minutes with an average tensile strength of 91.9 per cent., against 4 minutes' time and 89.8 per cent. strength when smith-welded.

The results of a series of tests of electrically welded metals carried on at the Watertown Arsenal[2] may be abridged as follows:

Twenty-nine broke at the weld.

Seventeen within 2 inches of the weld.

Eleven within the range of moderate heat.

Two near the grips.

Welds of wrought iron were 5 to 10 per cent. below unit strength; fracture fibrous or slightly spongy.

Welds of steel were from 50 to 80 per cent. less than unit strength.

Copper welded at 5 to 10 per cent. less than unit strength.

Steel welded to wrought iron at about the strength of the iron.

Brass gave an uncertain weld with wrought iron and had a strength at the weld of 8 1/2 to 16 1/2 tons to the inch.

[1] "Elec. Engineering Formula," p. 673.

[2] *Transactions of the American Society of Mechanical Engineers*, 1898, p. 97.

Steel welded with German silver with a strength of 20 tons to the inch.

Some welds of steel were about unit strength and some of iron were above unit strength.

A number of these bars had upsets, however, and the upset does not seem to have increased the strength very much.

When electric welding was first tried out there was serious complaint that the welds were burnt, spongy, and weak. This was due to the fact that the metals were melted together and were not worked. The welding machines with automatic swage blocks prevent crystallization at the weld, as does also hammering after welding. The weld is still liable to be weak on the edge of the heating radius. Many joints that will hold at the weld will break an inch either side because the heat has destroyed the properties of the metal.

PART III

HOT-FLAME WELDING

The Oxy-Acetylene Process

The oxy-acetylene welding process depends on the high heat of combustion of oxygen and acetylene. This process is by far the most efficient of the hot-flame systems, and it seems to be developed to its utmost. The apparatus primarily consists of:

1. Apparatus for storing or generating oxygen.
2. Apparatus for storing or generating acetylene.
3. A burner or blowpipe, with leading tubes, for the combustion of oxygen and acetylene.

This is the simple story, of which there are many details. The advantages and limitations of the processes here described are as follows:

1. The apparatus is fairly light, easily portable, and can be installed permanently.
2. For repair work, the cost is light and the results satisfactory.
3. On account of the intense heat of the flame, any substance or metal can be melted locally at once.
4. The high heat of the flame represents a limitation in so far as it is difficult to adjust and dangerous to use unless the operator knows his business.
5. The weld, being a melt-weld, is subject to oxidation and carbonization from the flame, and to crystallization on cooling.

The merits of the oxy-acetylene process greatly outweigh its possible faults. There is no process that will compare with it for welding job work of all kinds of metals and for repair work.

The present use of the oxy-acetylene flame, in welding and autogenous soldering is the outcome of the discoveries of many experimenters. It is a step beyond the oxy-hydrogen process: the flame has an approximate temperature of 3500 deg. Cent., while the oxy-hydrogen is about 2250 deg. Cent. But this high heat and the explosive nature of acetylene complicate the problem. Special apparatus had to be devised; special instructions

worked out for its use in practice. As one writer states, its practical value was at first overestimated by those interested in it. And when obstacles arose their ardor was checked and the process suffered a temporary relapse. At the present writing, however, the oxy-acetylene process is in a state of rapid development, and it has passed the critical stage. It is a recognized repair and welding process. It is being used to weld or solder almost all the metals, both to themselves and to one another; it is also used to cut through steel and iron plate, bars, etc., with six times the rapidity of a saw.

The oxy-acetylene process owes its present efficiency to the numberless inventions which have improved its torch, the constant pressure and water-seal (back-fire) valves, the generation and storage of oxygen and acetylene. Tanked oxygen is without doubt the handiest form for the welder; but cost, freight rates and the need of a steady supply in out of-the-way corners of the country all favor the production of oxygen by the potassium chlorate method. One company markets apparatus for making oxygen from chlorate. Practically all the welding firms use the tanked oxygen, made from the air.

Since 1880 industrial oxygen has been sold in increasing quantities by the firms using apparatus for the electrolysis of water. France and Germany have been specially active in projecting methods. The processes of Schuckert, Garuti, Schoop, and Schmidt are worthy of mention. In late years oxygen obtained by the Linde liquid-air process has come into competition with electrolytic oxygen. It is most largely used in this country, while the company claims to supply 90 per cent. of the world's demand for oxygen.

Acetylene was discovered in 1837. It was first recognized as a valuable illuminant, more especially in France, where it is used by hundreds of municipal plants at the present day. France is also foremost in oxy-acetylene welding inventions, among the most important being those of Fouché.

Acetylene can now be had in two forms: stored acetylene in steel cylinders, such as are used for carbon dioxid; and calcium carbid, which produces acetylene when wet with water, according to the formula—

$$CaC_2 + H_2O = C_2H_2 + CaO$$

Stored acetylene was originally a dangerous commodity. It

was liable to explode under pressure. The railroads objected to handling it. So the acetylene producer, calcium carbid, held the market. The gas was generated at the place where it was to be used and kept in a tank under less than 10 pounds' head. In 1897, the acetone-absorption process was patented, and since then stored acetylene has been in active competition with the carbid (see p. 112).

At the present writing a repair shop desiring to set up an acetylene welding department is offered a number of alternatives:

1. The acetylene can be bought in storage tanks or it can be generated from the carbid.

2. The oxygen can be bought in storage tanks or it can be generated from Oxygenite or by the other chlorate method.

APPARATUS

The Torch.—The invention of a suitable torch for this process has taken years of experimenting; only within the last year or so

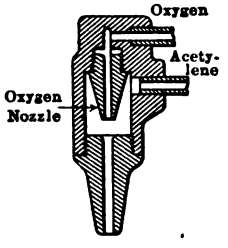


FIG. 53.—Low pressure or injection principle. (Henry Cave Iron Age.)

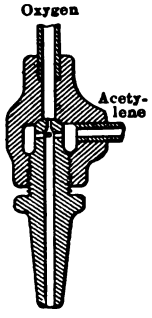


FIG. 54.—High pressure principle.

can it be said that the oxy-acetylene welder has had torches that give him the full benefit of his extraordinary flame. The flame is exceedingly hot, the gases are explosive, they must be mixed to a nicety; fortunately for the inventors of the torches these gases are not corrosive.

The first oxy-acetylene torch was invented by Mr. Edmond Fouché, who at the time was general manager of the Compagnie Francaise de l'Acetylene dissous. It was a high-pressure torch because they were then using acetylene compressed in acetone

tanks under several atmospheres. It was quite easy to get a good mixture with both gases entering the torch under many pounds pressure. Several years later Fouché went with another company which used acetylene direct from the generator and under the low generator pressure. So he had to devise a low-pressure torch. This torch received its oxygen under high pressure, which, entering a chamber in the torch, expanded and drew acetylene from the acetylene orifice under the injector principle (Fig. 53). These were the pioneer torches. They were imperfect in principle: The high-pressure torch mixed the gases at the haft and they passed the entire length of the torch in a mixed state. This was necessary under the high pressure to get a perfect mixture. But if at any time the velocity of the mixed gases toward the nozzle was less than the velocity of the burning, there was a back-fire and the entire torch would quickly burn unless turned off at once. Back-firing occurred when the tip was held too close to the work. On the other hand, the low-pressure torch

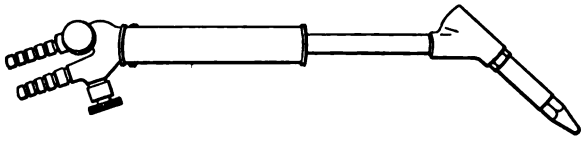


FIG. 55.—Injection type high or low pressure torch. (Oxweld Acetyline Co.)

was apt to send an excess of oxygen into the flame, which then burned the weld.

Later on the firm of A. Boas Rodrigues & Compagnie, of Paris, devised a medium-pressure torch, in which oxygen was used at high pressure and acetylene at about 3 pounds. This allowed the mixing to be done close to the nozzle. The old torches were made in a number of sizes to suit the need.

There are now used in this country the three following styles of torches:

1. The original Fouché torch, improved, in which the gases are mixed as they enter the haft.

2. The low-pressure torch (also invented by Fouché) on the injector principle (Fig. 55), and acetylene at the generator pressure of less than a pound.

3. The "positive-pressure" torch (French medium pressure) with acetylene up to 10 pounds and oxygen stepped down from 120 atmospheres to one or two atmospheres (Fig. 56).

Besides these torches there is the special cutting torch, which carries an extra jet of oxygen at high pressure. In this torch the welding flame becomes a preheating flame and is so disposed as to be in advance of the cutting jet (Fig. 57).

The modern torch, as will be noted by the figures, is a handy tool; the gases are regulated or cut off by cocks at the handle. In some of these torches the gases, either mixed or before mixing, pass through a packing of wire gauze, asbestos, or similar mate-

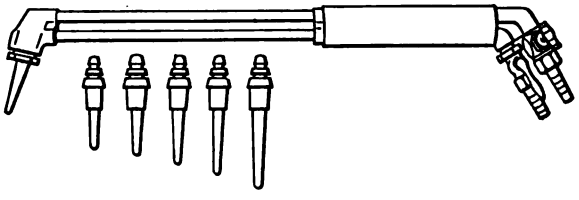


FIG. 56.—Oxy-Acetyline welding torch. (Davis-Bournonville Co.)

rial, which is intended to prevent flash-backs into the retaining tanks, acting on the principle of the Davy lamp. The torch proper is made in several standard sizes. Each torch has a graduated series of removable tips to give the operator a wide range in the size of his flame. These tips either screw in or are made to fit by adhesion.

The cutting torch formerly consisted of the regulation torch with the addition of a special tube and nozzle carrying oxygen

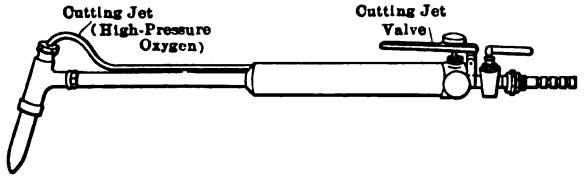


FIG. 57.—Cutting torch. (Oxweld Acetyline Co.)

at high pressure. As the cutting nozzle was fitted on rigidly the operator had to hold his torch in a given direction to cut, because the heating torch must always preheat the metal. One recent type of cutter has its cutting nozzle surrounded by a ring of heating nozzles, so that the metal is heated ahead of the cutter no matter how the operator works. Another improved cutter has two supply tubes only, and the oxygen for cutting is released by thumb pressure on a valve on the handle of the torch.

The nozzles of all oxy-acetylene torches suffer in time from the intense heat of the flame. Constant back-firing, caused by holding the torch too close to the work, will soon burn out the tip. Pieces of melted metal will get in the tip and must be removed with a brass or copper piece—not steel. The heating effect of back-firing on the nozzle, or of heat radiating back from the work, has lately been overcome in a special water-cooled torch (Fig. 58). The torch is a very sensitive tool, but it will last a long time if well used.

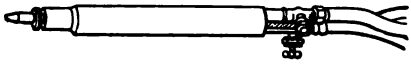


FIG. 58.—Water-Cooled machine welding torch. (Davis-Bournonville Co.)

Tables 20 and 21 give an idea of the range of pressures of both gases for different sized flames, for high, medium and low pressures, and also the amounts of gases consumed, the amounts of work welded or cut, and the unit costs.

TABLE 20.—APPROXIMATE COST OF MACHINE CUTTING
(Davis-Bournonville Co.)

Oxygen at 3c., Acetylene at 1c. per cu. ft.

Thickness of steel, inches	Pressure of cutting oxygen, lb. per sq. in.	Pressure of heating oxygen, lb. per sq. in.	Cubic feet oxygen per foot of cut	Cubic feet acetylene per foot of cut	Inches cut per minute	Cost of gases per foot of cut
¼	10 lb.	4 lb.	0.40	0.086	24	$0.013
½	20 lb.	4 lb.	0.91	0.15	15	0.029
¾	30 lb.	4 lb.	1.16	0.15	15	0.036
1	30 lb.	4 lb.	1.45	0.172	12	0.045
1¼	40 lb.	4 lb.	2.64	0.192	8	0.081
1	20 lb.	5 lb.	1.25	0.27	18	0.040
1¼	30 lb.	5 lb.	2.40	0.38	12	0.076
2	40 lb.	5 lb.	2.96	0.38	12	0.093
3	50 lb.	5 lb.	5.37	0.57	8	0.167
3	40 lb.	5 lb.	7.23	0.75	8	0.224
4	50 lb.	5 lb.	9.70	0.80	7	0.299
5	60 lb.	5 lb.	15.00	1.00	5	0.460
6	70 lb.	6 lb.	21.09	1.50	4	0.648
7	80 lb.	6 lb.	25.00	1.50	4	0.765
8	90 lb.	6 lb.	28.50	1.50	4	0.870
9	100 lb.	6 lb.	43.20	2.00	3	1.311

TABLE 21.—APPROXIMATE HOUR COST OF OXY-ACETYLENE WELDING

Oxygen at 3 cents per cu. ft.; Acetylene at 1 cent per cu. ft.

Thick of metal inches	Acetylene pressure lb. per sq. in.	Oxygen pressure lb. per sq. in.	Acetylene consumption in ft. per hr.	Oxygen consumption cu. ft. per hr.	Lineal feet welded per hr.	Cost of of gases per hr.	Cost of of gases per lin. ft.
1/32	1	2	3.21	3.65	30	0.1416	0.00472
1/16	2	4	4.84	5.50	25	0.2134	0.00854
3/32	3	6	8.14	9.28	20	0.3598	0.01799
1/8	4	8	12.50	14.27	15	0.5531	0.03687
3/16	5	10	17.81	21.32	9	0.8177	0.09085
1/4	6	12	24.97	28.46	6	1.1035	0.18392
5/16	6	14	33.24	37.90	5	1.4694	0.29388
3/8	6	16	41.99	47.87	4	1.8560	0.46400
1/2	6	18	57.85	65.95	3	2.5570	0.85233
1/2 up	6	20	82.60	94.05	2	3.6465	1.82325

Each torch calls for given lengths of wire-wound rubber hose of superior quality. Where a portable apparatus is used or in repair shops where the work is brought to the welding table shorter lengths can be used.

Several companies also market special preheating apparatus, to be used in connection with welding. This consists of an oil or gasoline tank on a truck, valves, hose and a vaporizing torch. These preheaters are quite necessary for many jobs, especially copper, aluminum and cast iron.

Goggles are also necessary for the eyes and gloves for the hands. Besides the heat of the metal and the sparks from it, the operator needs protection from the intense glare of the flame.

Valves.—Where tanked gases are used under pressure, each tank has its pressure-registering valve and constant-pressure regulator, commonly as a one-piece apparatus (Fig. 59). The first-named valve simply shows the pressure in the gas tank when the tank cock is open; while the constant-pressure regulator is an adjustable valve which is set by a screw to deliver gas to the service hose at a certain pressure, for instance not over 40 pounds per square inch. This valve is an absolute necessity

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because it delivers the right pressure to the operator, no matter what the pressure in the tank.

Another valve which is found on each tube of every torch is called the back-pressure valve or water seal (Fig. 60). If for any reason the gases were forced backward from the torch or should burn backward, the gas or flame could go no further than the water valve.

"The action of the hydraulic back-pressure valve is apparent from Fig. 60. The cock on the acetylene pipe from the gas-holder is con-

FIG. 59.—Oxygen constant-pressure regulator.

nected to the inlet at *B*, and the acetylene pipe leading to the blowpipe is connected to the outlet *C*. *D* is a priming cup through which water can be poured into the chamber until it overflows at the cock *F*. The cock on the service line at *B* must be closed while the chamber is being filled with water. When water shows at the cock *F*, it must be closed and the cock at *B* opened. The valve is then in working order.

"The pipe *G*, leading from below the seal at *E* to priming cup, is made of sufficient length to hold a column of water equal to the pressure in the acetylene holder, which would be equal to not less than 12 inches of water, and in no case should exceed 20 inches.

"In cases where two or more blowpipes are worked from the same acetylene supply pipe, a separate back-pressure valve should be employed for each welding station."

Machine Welders and Cutters.—Since the first edition of this book the oxy-acetylene companies have devised a number of machine welders—machines which carry the torch at work and displace hand welding and cutting. These machine welders mark a decided advance in certain kinds of work, such as the welding of sheet metal or the cutting of sheet metal according to pattern. These machines need an attendant to regulate the flame and watch the work, just as the automatic Thomson machines need an attendant, but the welding or cutting is done at a predetermined uniform rate which not only saves gas, but makes a much safer and more uniform weld. Just as with the Thomson machines, these automatic gas welders and cutters are designed for special purposes, though the principle is, as above stated, that of the uniform advance of the working flame. Thus firms that have continuous runs of repeat work, such as pipes, barrels, seamless cylinders, cans, boilers, etc., have a machine designed for that special purpose.

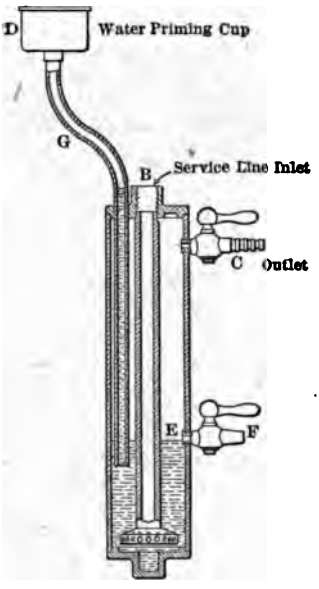

FIG. 60.—Diagram of a safety water seal, to protect the acetylene supply. (The Linde Air Products Company.)

Figs. 61 and 62 show two types of automatic or machine cutters. Fig. 61 is a cutter which consists of a rigid beam on which is mounted the propelling screw carrying the cutting torch. This torch travels in a straight line at a uniform speed and makes a sharp, clean cut like a saw cut. The maximum length of the cut is 5 1/2 feet, and a transverse cut of 14 inches.

There are two types of rail cutters recently invented. One, the *railagraph*, cuts rails. This machine will cut a 12-inch I-beam in about 3 minutes. The other, the *holograph*, cuts holes in the web of rails or structural iron not more than 3/4 inch thick. It is specially adapted to railroad, bridge and structural steel work.

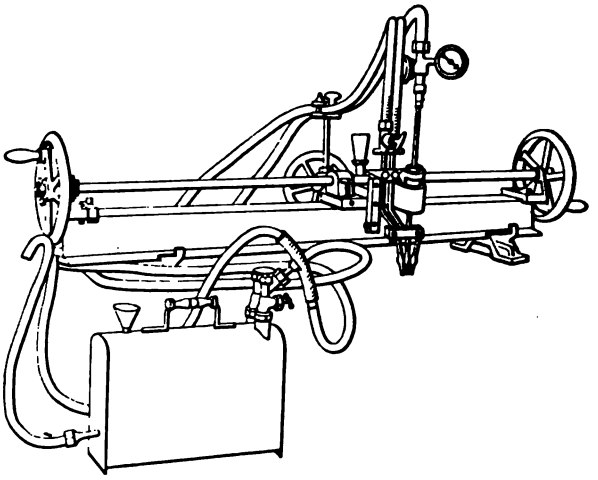

FIG. 61.—Line cutting machine. (Oxweld Acetylene Co.)

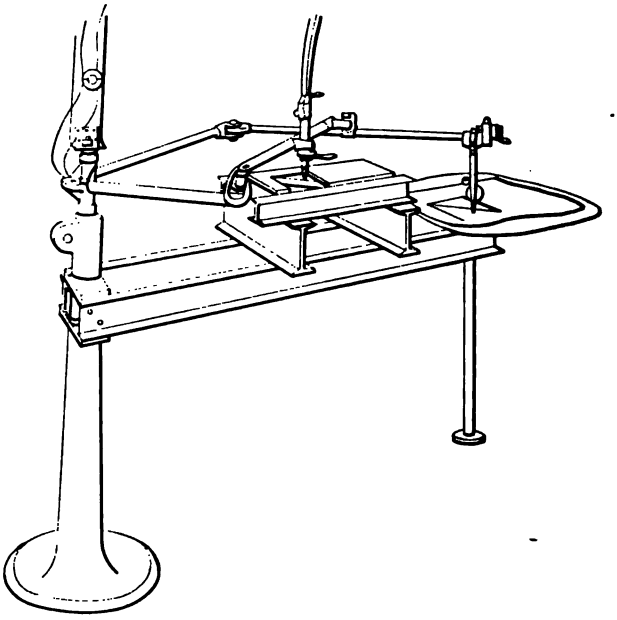

FIG. 62.—The oxygraph. (Davis-Bournonville Co.)

Fig. 62 shows the *oxygraph*, designed on the principle of a pantagraph to cut irregular patterns in steel.

"The *oxygraph*[1] is a recent development effected by the Davis-Bournonville Co. for cutting steel by the oxy-acetylene process. It is constructed on the pantagraph principle and is so arranged that steel of several inches thickness can be cut to any desired shape by simply guiding the pantagraph arm, which is equipped with a cutting torch and a mechanically propelled tracer. When the steel is to be cut accurately to a given shape, a drawing is placed on the table of the machine, and, as the operator guides the tracer along the outline of the drawing, the cutting torch is given a corresponding movement on a reduced scale. In this way, intricate shapes can be cut with considerable rapidity.

"The oxygraph is very simple, both as regards its construction and operation. It consists of a heavy cast-iron column and an outboard standard, upon which are mounted horizontal supports for holding the work. At the left end of the work-table, the pantagraph arm is pivoted, and at the opposite end there is a steel table for holding the drawing corresponding to the outline of the form to be cut. The tracing wheel, which is a thin steel disk, is attached to the outer end of the pantagraph arm and rests on the drawing-table. This wheel is positively-rotated by a small motor attached to the end of the horizontal arm, and it can be swiveled about a vertical axis for moving in any required direction. This mechanical propulsion of the tracing wheel is a novel and valuable feature and has two decided advantages: In the first place, it provides a uniform predetermined speed for the cutting torch, so that the latter moves at the proper rate to obtain the greatest efficiency; and, in the second place, it is much easier for the operator to follow the lines on a drawing, because his entire attention can be given to the control of the tracing wheel, the latter simply being turned one way or the other, as may be required. The motor is connected with the tracing wheel through small gearing and shafts, and it is started or stopped by a switch conveniently located above the wheel. The motor is small and compact and requires very little power. It can be operated either by a small storage battery or a wire attached to an electric light fixture.

"This machine will cut steel 3 inches thick at a speed of 6 inches per minute, and the company expects to increase this capacity considerably. It should be mentioned that the cutting is done with the oxy-acetylene flame and the oxygen cutting jet, the same as in ordinary practice, although the torch is designed especially for use with the oxygraph. The tip of the torch has five jets for heating and one larger oxygen cutting jet. The heating jets are arranged in a circle around the

[1] *Machinery*, July, 1912.

central cutting jet, so that a heating flame precedes the oxygen jet regardless of the direction in which the torch is moved, and another heating flame also follows the oxygen jet. It has been found that this arrangement of a heating jet in front and another to the rear of the oxygen jet is much superior to the usual one."

Straight lines, curves or right-angle turns can be followed by an inexperienced operator. This is made possible by the mechanically propelled tracing wheel, which simply needs to be guided, but takes care of itself as far as the forward movement is concerned. When a corner is reached, the wheel is given a quick turn, and, being motor-driven, immediately starts off in the other direction, so that the corner is cut clean and sharp, which would not be the case if there were any delay. The sides of the narrow path or kerf left by the flame, are remarkably smooth.

"The pantagraph arm is made of light steel tubing, and the joints are provided with ball bearings to give a free movement. The arm can be adjusted vertically to suit the height of the work, and the drawing-table also has a vertical adjustment. The torch tip is about ⅛ inch above the metal when in operation, and the latest designs will have a fine, vertical adjustment of the torch so that its height can be varied in case the material being cut has an uneven surface. This machine has a capacity for widths up to 18 inches, without moving the piece being cut."

Portable Outfits.—Recently several firms have put small portable outfits on the market. These outfits are mounted on trucks and consist of tanks of the two gases and the complete apparatus for cutting and welding. The tanks are charged at a stationary generating plant and are then ready for service at points out of reach of the stationary plant. One type of portable plant carries a small acetylene generator of its own. The need of such apparatus for railroads, shipyards, large foundries, fire stations, construction camps, etc., suggests itself at once.

Metals and Fluxes.—This process will weld practically all metals and alloys. This at once suggests that some of the metals to be welded will have to be protected from the air and from the very hot flame by suitable fluxes. Thus brass, copper, aluminum, cast iron, high-carbon steel, etc., all need the protection of a flux.

Moreover, since most welds need to have metal added to them to build them up or to fill cavities, it is necessary to have this added metal either of the same composition, or else of a special composition to meet the needs of that weld.

The compounding of these melt bars and special fluxes has called for considerable ingenuity. The difference between a

perfect weld and a defective weld lies as much in the use of the right materials as it does in the skill of the operator. Especially in the welding of iron and steel the operator has to be careful that his melt bar is not an alloy of the wrong sort. Iron is often far from being iron.

GASES

Oxygen by Electrolysis of Water.—When water is decomposed by electrolysis, it gives 2 volumes hydrogen, 1 volume oxygen.

The electrolyte is a dilute solution of sodium or potassium hydroxid; oxygen rises from the positive and hydrogen from the negative. If the gases are collected as mixed oxygen and hydrogen in the gasometer, it is called *detonating gas.* This is the gas that was first used in the oxy-hydrogen blowpipe (see page 143). Detonating gas is handy for blowpipe work, but it is dangerous. It is the most readily combustible mixture of the two gases, and if the torch backfires there will be an explosion. To prevent this a safety water-seal was introduced in the leading tube, or the blowpipe handle contained a chamber packed with fine rods or gauze or asbestos wool to imitate the idea of the Davy safety lamp.

The railroads will not handle detonating gas, and it is not manufactured except privately. In the electrolysis of water nowadays a diaphragm placed between kathode and anode separates the gases. Of these gases the oxygen is of the greater commercial importance.

Oxygen is colorless, odorless, non-poisonous, and supports combustion with hydrogen, acetylene, producer gas, etc.

Since 1880 rapid progress has been made in the manufacture of nearly pure oxygen and hydrogen by the electrolysis of water. Abroad, it is the main source of these two gases, especially since 1900. In America the Linde oxygen practically controls the market though electrolytic oxygen is coming to the front.

Among the successful commercial processes in Europe are those using the patents of Schmidt, Schuckert, Garuti, Schoop, and Hazard-Flamand. The Schuckert apparatus is as follows:

"It consists of a cast-iron tank, containing a number of cast-iron electrodes in various chambers separated by diaphragms, extending from the top downward about three-fourths the depth of the cell, the gases being conveyed through a pipe system to separators, whence the wash-water is returned to the electrolytic cells.

"The electrolyte is a 20 per cent. solution of caustic potash. The cells are embedded in a sand layer about 2 or 3 inches in thickness, arranged to protect the apparatus from heat radiation, the temperature of the electrolyte being maintained at about 75 deg. Cent. This is said to be the most satisfactory temperature, as the lowest voltage is required at this temperature for decomposing the electrolyte. The pressure is from 2 to 3 volts, and the various cells are connected in series very much the same as a battery of accumulators. The hydrogen and oxygen gases when generated at the electrodes are conducted through pipes to separate gasometers or tanks for storage."[1]

From 97 to 99 per cent. oxygen is claimed for this plant, which is that of the Schuckert Co., Nürnberg, Germany.

Another process, the Hazard-Flamand is also described in detail in *the Electro-Chemist and Metallurgist*[2] of the British Faraday Society. The table of relative outputs at different current values is given below.

TABLE 22.—THE HAZARD-FLAMAND CELL

Volts applied at voltameter terminals	Current in amps.	Yield of O_2 grams per hr.	Yield of O_2 grams per kw.-hr.	Per cent. of theoretical energy efficiency (213.07 grams per kw.-hr.)
2.1	243	72.0	141.7	66.5
2.3	265	79.0	129.6	60.7
2.8	323	96.2	106.3	50.5

"In considering the fourth and fifth columns, it must be borne in mind that hydrogen is also liberated, of double the volume, but of 1/8 the weight. In other words, with an e.m.f. of 2.1 volts, each voltameter produces 1.8 cu. ft. of oxygen per hour and 3.6 cu. ft. of hydrogen, of the respective approximate weights of 72.0 and 9.0 grams." The article goes on to state that while 2.1 volts is theoretically most efficient, 2.4 gives best practice. The oxygen is 99 per cent. pure and the hydrogen in proportion.

Manufacturers of electrolytic gases claim that their oxygen is much purer than that of other processes. Oxygen by the chlorate process is contaminated with carbon dioxid and chlorin, often over 10 per cent., before being scrubbed in a caustic solu-

[1] *Electrochemical and Metallurgical Industry*, F. C. Perkins, May, 1906.
[2] *Electro-chemist and Metallurgist*, June, 1904.

tion. Liquid-air oxygen contains from one to five per cent. nitrogen. The impurities of electrolytic oxygen are a few per cents. of hydrogen, a little chlorin, and water vapor. In laboratory determinations these impurities sometimes determine which kind of oxygen shall be used. For welding and soldering, the gases should be pure for the sake of keeping harmful impurities from burning into the metal.

The first cost of installation of an electrolysis plant is very great and may reach as high as $25,000, exclusive of maintenance cost. For this reason very few industries would find it worth while to install such a plant for welding purposes. In Europe these installations are most often separate concerns for the manufacture and sale of stored oxygen and hydrogen.

For further information about electrolysis of water the reader is referred to "The Electrolysis of Water," by Engelhardt, translated by Richards, 1904.

Oxygen from Air.—Oxygen can be bought in steel cylinders. There are two industrial processes at present for making oxygen. It can be drawn from the atmosphere by the liquid-air method or it can be produced by the electrolytic decomposition of water. This latter method to which there are many variations is largely used in Europe.[1] The patents for the former method are owned and operated under, in this country, by The Linde Air Products Company.

By the Linde process the atmosphere is compressed by a double-stage pump up to 1800 pounds. This compression raises the temperature 1 deg. Fahr. for every 2 atmospheres pressure. The compressed air is cooled by ice and salt (for small plants) or by ammonia (for large plants). If this air, then, at 1800 pounds and about 15 deg. Cent., be expanded, the temperature will drop considerably. If some is expanded on the outside of a cylinder under the same pressure, the air in the cylinder will be lowered in temperature and will liquefy because it is under pressure. Liquid air consists of approximately 80 per cent. nitrogen critical temperature—149 deg. Cent.; and 20 per cent. oxygen, critical temperature—119 deg. Cent. The oxygen is then separated by fractional distillation similar to the rectification of spirits.

Storage oxygen gas can be obtained in cylinders of sizes and weights shown in the following table:

[1] "Electrolysis of Water," Victor Engelhardt, 1994.

TABLE 23.—OXYGEN IN CYLINDERS
(The Linde Air Products Co.)

Contents in cubic feet	Approximate weight in pounds (empty)	Price of cylinder with valve	Rent per week after the first month
5[1]	6	$6.50	.....
25	38½	8.50	$0.50
50	62	12.00	0.75
100	132	20.00	1.00

The oxygen is under pressure of 120 atmospheres. It is guaranteed 95 per cent. pure, the residue being nitrogen. As nitrogen is inert and not in sufficient quantity to absorb heat or retard action, its presence is neg igible.

These tanks may be rented and the oxygen bought or both gas and tank bought outright. In either case the company will recharge them, subject to certain conditions. On account of the very high pressure, the cylinders are annealed at least once in four years, and are carefully inspected and labeled on charging. Each tank must have reducing valves and, when in use, pressure gauges. The railroads receive them charged as second-class merchandise, and discharged as fourth class, on account of the pressure.

The factor of safety is large with these tanks, but nevertheless they must be kept in a cool place. In the heat of the direct sun's rays the pressur e will greatly increase.

The present price of this stored oxygen is from two and one-half to four cents, depending on the quantity bought. Rent is charged on the tanks after the first month. This is exclusive of transportation. The advantage of having a large volume of oxygen, in small bulk, when a generator is unhandy or expensive, is very apparent. The principal disadvantage is the possibility of leakage, which is a variable factor. Datum is not at hand, but it is common opinion that tanked oxygen is at least several per cent. purer than that produced by the chlorate process.

Oxygen from Chlorate.—One firm, the Davis-Bournonville Co., markets apparatus for making oxygen from potassium chlorate. This process may be cheaper in the long run for those firms using constantly a considerable amount of oxygen for

[1] This size of cylinder cannot be hired.

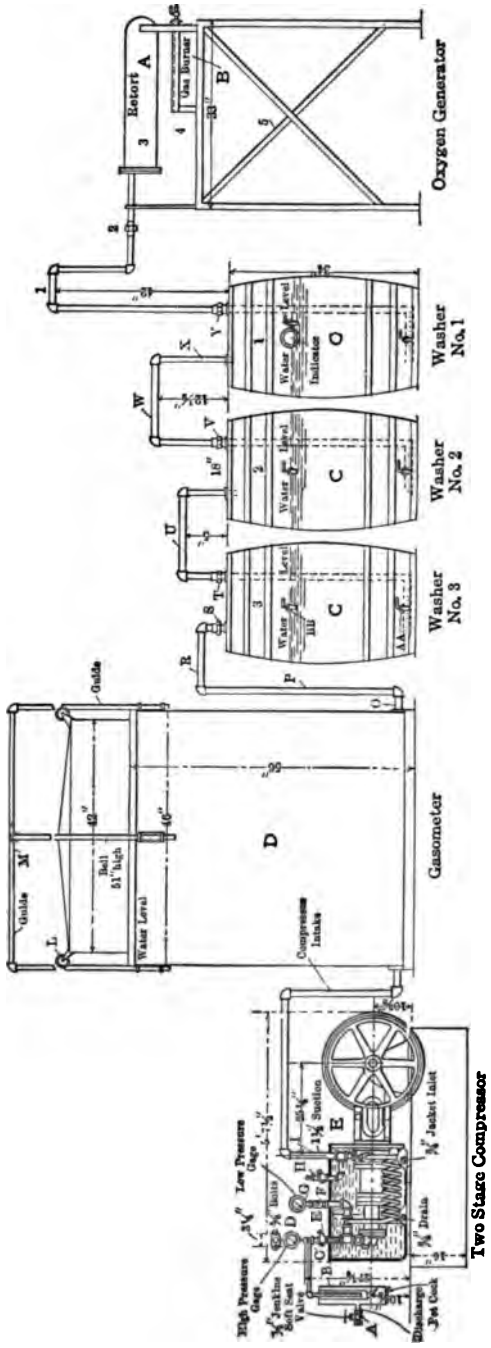

FIG. 63.—Diagram of oxygen generator. (Davis-Bournonville Company.)

welding or other purposes, especially for isolated places where tanked oxygen may not be easy to get. Oxygen is produced from potassium chlorate according to the formula:

$$2KClO_3 + \text{heat} = 2KCl + 3O_2,$$

and from manganese dioxide by

$$3MnO_2 + \text{heat} = Mn_3O_4 + O_2.$$

Manganese dioxide is mixed with the chlorate in this reaction for oxygen because it reduces the temperature of occlusion and prevents the chlorate from melting and flashing. This mixture, which is heated with a gas flame, is composed of potassium chlorate, 100 parts, and manganese dioxide, 13 parts; both should be fairly pure to insure a gas of 97 to 98 per cent. estimated purity after three scrubbings.

Fig. 63 shows the apparatus in position. The oxygen mixture is charged into the retort, which should be as full as possible to exclude ordinary air. The retort is heated with a slow gas flame so that the generation is regular; as the heating proceeds the flame is raised to drive off the last of the oxygen. The oxygen generated passes through three washer tanks filled with sodium hydroxide solution, and then into a gasometer. From the gasometer the gas is compressed by a two-stage compressor into pressed-steel cylinders, at a pressure of 300 pounds to the inch. This for the reason that considerable pressure is needed to make a good jet flame, especially in cutting metals.

The advantages claimed for this process are: that there is little oxygen lost when the retort is recharged, because the pressure is low in all of the chambers; that loss from leakage is much less; that the bubbles of gas being much more expanded in passing through the hydroxid solution are washed much more thoroughly.

One writer[1] estimates the cost of the oxygen mixture, when made from fairly pure chemicals, at eight cents a pound. One pound producing 4 to 4 1/2 feet, brings the cost of the oxygen to about 2.25 cents a cubic foot. This is exclusive of freight and operating charges.

Oxone.—Very pure oxygen can be generated on a small scale by wetting sodium peroxid.

$$4NaO + 2H_2O = 4NaOH + O_2.$$

[1] *American Machinist*, Henry Cave.

The Oxone idea is a recent development of an old method. The sodium peroxid in fused lumps is delivered in hermetically sealed cans to protect it from the moisture. Each pound of Oxone produces over 2 feet of the gas, at a price of from 13 to 20 cents a foot.[1] The generator (Fig. 64) is made by the Nel-

FIG. 64.—Oxone oxygen generator. (The Roessler & Hasslacher Chemical Company.)

son Goodyear Company and sold by the Roessler & Hasslacher Chemical Company.

To make oxygen several holes are punched in the top and bottom of the can and it is placed in the generator. The generator is filled with water to the mark, closed and the needle

FIG. 65.—Oxygen burner. (The Roessler & Hasslacher Chemical Company.)

valve opened. Opening the valve lets water in on the Oxone, and oxygen begins to come off. It is claimed to be 99 per cent. pure; the trace of water vapor is removed by washing, and the delivered gas is then practically pure. The safety valve of the

[1] Special Information.

generator is set at five pounds and the delivery valve at three. Closing the needle valve stops the generating. Soda lye is the by-product. In cleaning out the generator be careful not to get the strong lye on the hands nor clothing.

This oxygen is expensive, very pure, and the apparatus easily portable. Hence it can be used to make gas for reinforcing the air in submarines or under-ground or under-water workings and by jewelers, dentists, assayers, and silversmiths. For burning this oxygen the company furnishes a special torch (Fig. 65). The other gas of combustion is sulphuric ether; or acetylene, gasoline vapor, or coal gas can be used. The oxygen-ether flame is ideal for jewelers and dentists. Fig. 66 shows a handy furnace for melting down metals.

FIG. 66.—Oxone furnace for dentists and jewelers. (The Roessler & Hasslacher Chemical Co.)

Acetylene.—Acetylene is a heavy, combustible gas with a strong odor, and was first made by Davy in 1837. It is produced by the reaction between water and calcium carbid according to the formula—

$$CaC_2 + H_2O = C_2H_2 + CaO.$$

The principal impurities of the freshly generated gas are ammonia and hydrogen phosphid and sulphid. These are removed by washing the gas in different solutions which will react upon these gases.

Acetylene is endothermic. So that the great heat of its combustion is the sum of its endothermic factor and the factor for carbon monoxid or dioxid. For this reason acetylene burns with tremendous heat with oxygen. The intense white light of combustion in air is attributed to the nascent carbon particles.

Mixed with air, acetylene is explosive between the range of 2 per cent. gas, 98 per cent. air; and 49 per cent. gas, 51 per cent. air. This is a very wide range and makes the gas a troublesome one unless used with care. The odor, which is attributed to a small proportion of hydrocarbons, is offensive, but helps to detect leakage. Though there are instances of asphyxiation by this gas, it has been shown that pure acetylene is not a poisonous gas.

The Acetylene Generator.—In repair shops, where acetylene will be needed continually for the work at hand, it is best to install an acetylene generator. One of the types approved by the underwriters should be selected. It should be placed in a separate shed outside of the shop. This will safeguard the workman and the building in case of accident. Nowadays, however, acetylene can be used with perfect safety, provided there is ordinary good sense employed in the installation and use of it.

There are two general types of generators: one in which powdered or granular calcium carbid is fed into water, the other in which water is dropped upon the carbid. The reaction generates considerable heat. This is the element of danger. For this reason, perhaps the safer generator is the style first named, in which the carbid would be quenched in water while giving off the gas. One part of carbid will boil six parts, by weight, of water. Furthermore, water-feed generators give off gas long after the water is stopped, and carbid-feed only for a short time.

Some carbid contains phosphates which are decomposed with the formation of hydrogen phosphid. This gas, which comes over with the acetylene in small quantities, is said to have a bad effect on the metals to be welded. While tanked acetylene has been cleansed of both hydrogen phosphid and sulphid, the generator acetylene is not. It is important to use in the generator a carbid that is quite pure chemically. The presence of small quantities of phosphorus can be easily told by the white smoke it adds to the acetylene flame. Sulphur cannot be so easily detected.

One pound of lump carbid gives 4 1/2 feet of gas. One pound of *ground* carbid only 4 feet,[1] due to previous decomposition. At this writing the cost of carbid per hour is about 4/10 cents for a 24-candlepower burner consuming 1/2 foot of gas.[2]

[1] Rules of National Board of Fire Underwriters.

[2] Davis Acetylene Company, special information.

There are a number of good generators on the market, and the purchaser can make his choice from them. The Davis generator is at present recommended by the Davis-Bournonville Company. This is a lump-carbid feeder made in sizes ranging from the portable size, charged with 20 pounds of carbid, up to the largest size of 300 pounds' carbid capacity (Fig. 68). Lump

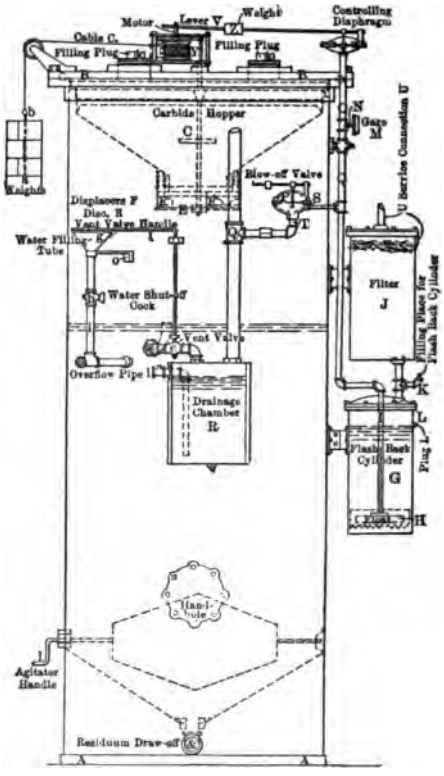

FIG. 67.—Diagram of carbid-feed acetylene generator. (Davis Acetylene Co.)

carbid, 1 1/4 by 3/8 inches, is charged into the hopper at the top, whence it slides down an inclined plane onto a circular plate. This plate hangs on an axle, which rotates it according to the working of the overhead motor, and the carbid is brushed off the edge of the plate when it rotates. A pressure diaphragm controls the feeding apparatus. The operator sets the diaphragm for a given pressure by an adjustable spring controlling the dia-

phragm. The pressure of the gas can be raised to 15 pounds, is uniform, and is safe-guarded by a blow-off. The water levels are also maintained by overflow pipes. The act of opening the hopper to charge the machine locks the motor, while the position of the motor weight shows at once how much carbid is left in the hopper.

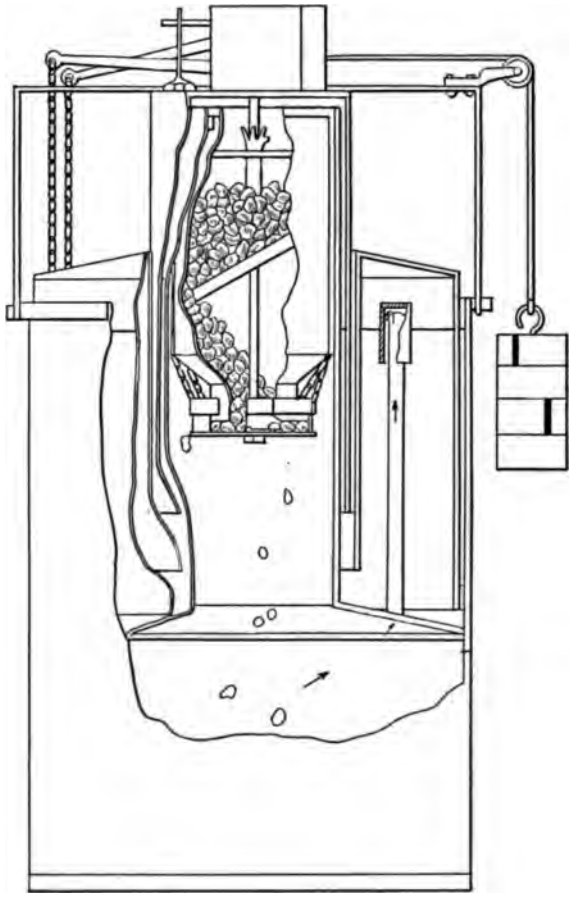

FIG. 68.—Diagram of hopper and feed mechanism, Davis carbid-feed acetylene generator.

The advantages claimed for this generator are:

1. That being carbid-fed, the resultant gas is always of a safe temperature, because of the great excess of water it is quenched in.

2. The use of lump carbid ensures slower generation, which

takes place after the lumps have gone to the bottom. And lump carbid gives at least 10 per cent. more gas than the pulverized stone.

3. The feed motor is effective: the carbid cannot be overfed and is fed as the gas is needed.

4. The water levels are automatically maintained.

5. All parts are accessible.

6. The charging hopper is perfectly sealed from leakage.

This generator should be installed in a shed outside of the building where the welding is carried on. The shed should be of sufficient size to allow easy access to all parts of the generator, and should be steam-heated with pipes coming from without, so that the water will not freeze up in the winter. No light or fire must be allowed in or near the shed, because of danger from explosions. The shed should be kept locked and closed to all but the regular attendant, who is an experienced hand.

Acetylene gas is much more dangerous than the other illuminating gases, as it will readily explode in mixtures of more or less air than the other gases. Accidents are not so common now as formerly, but happen often enough to show that there is much carelessness in the installation and management of generators, The underwriters' associations of this country and abroad are very rigid in their specifications concerning acetylene generators.

Dissolved Acetylene.—Acetylene dissociates at 780 deg. Cent. into carbon and hydrogen; under pressure of two atmospheres or more, the gas is tricky and is liable to explode. But acetylene is readily soluble in a number of liquids, among them acetone. Acetone is fairly cheap, inert, and incombustible—very essential properties. It boils at 56 deg. Cent., has a strong affinity for acetylene, and is not decomposed by it. At atmospheric pressure and 15 deg. Cent. acetone dissolves 24 times its volume of acetylene. At 12 atmospheres, which is the pressure given the storage cylinders, it dissolves about 300 volumes of the gas and increases in volume 50 per cent. The pressure of such a tank is doubled with every rise of 30 deg. Cent., while undissolved acetylene triples its pressure for each rise of 8 deg. Cent.

Berthelot and Vielle[1] experimented with the solution of acetylene in acetone and found that it could not be exploded with an electric spark though under high pressure. Hutton[2] says that,

[1] *Elec. and Metal. Industry*, March, 1903.

[2] R. S. Hutton, *Elec. and Metal Industry*, April 1913.

"In practice 1000 liters of acetylene carry off the vapor of 0.06 liter of liquid acetone"—not an appreciable amount.

All of the above characteristics of the solution recommend acetone as a solvent or body for the storage of acetylene for commerce. The French government was the first to officially recognize acetone storage tanks as safe. The railroads of this country now accept the cylinders for carriage as non-explosive.

Acetone storage was worked out by the Belgian chemists Claude and Hesse, and patented by them in 1897. The principal difficulty to overcome was the factor of expansion of the solution with increased acetylene content, and the corresponding shrinking as the acetylene was drawn out of the tank. The cylinder would be full at 12 atmospheres and only two-thirds full under normal pressure. This meant that a considerable part of the tank would contain the gas alone, subject to the danger of explosion. To overcome this, the cylinder was filled with a porous or absorbent body, which was saturated with the acetone-acetylene solution. Porous brick or stoneware of four-fifths porosity was used; also charcoal cake, bound together with soluble glass; in this country asbestos fiber with soluble glass binder is used. These absorbents will all carry from 50 to 80 per cent. of the solution per volume. When the acetylene is all drawn off, the tank is still perfectly safe and can be recharged simply by passing in acetylene under pressure.

The tanks themselves are pressed-steel cylinders, such as are used for soda-water, and are fitted with cocks and a pressure-regulating valve. They are delivered under 10 atmospheres' pressure, and contain about 100 volumes of the gas—considerably below the saturation content of acetone at that pressure. They should be kept in a cool place, out of the sunlight, because the pressure doubles with 30 deg. rise of temperature. If exposed to too great heat, the pressure might rise to the danger point, and an explosion take place.

Carbid will produce about 4 cubic feet of acetylene per pound; the present price is below four cents a pound. This brings the material cost to about one cent per cubic foot of gas. Stored acetylene costs about twice as much, but its adaptability is much greater and in many cases much more than nullifies the difference. It is claimed to be the purest form of the gas, being practically free from sulphur and phosphorus, because it receives four to six washings.

Acetylene storage tanks are of the following size and capacity:

TABLE 24.—ACETYLENE STORAGE TANKS

Diameter in inches	Length, inches	Capacity, cu. ft.	Weight, pounds
7	24	50	50
8	30	80	75
10	30	125	105
12	36	225	120
14	48	400	349
16	48	500	435

PRACTICE

The Flame.—Since the introduction of this system its field of usefulness has greatly widened and it calls for a corresponding skill on the part of the operator. The first thing he learns is how to adjust his flame. The proportion of acetylene to oxygen varies from 1 acetylene to 1.50 or more oxygen in the injector low-pressure type, to 1 of acetylene to 1.14 oxygen in one type of high-pressure torch, called the positive pressure. As noted on page 140, the exact proportion of acetylene to oxygen cannot be stated for the simple reason that no one knows the formula of combustion or the composition of the residual gases. It is supposed to be about 2.50 of oxygen to one of acetylene. But this mixture actually gives a highly oxidizing flame. If the flame has an excess of free oxygen beyond the cone this oxygen will burn the molten metal. If there is too much acetylene in the flame to burn completely, it will split up and some elementary carbon from it will enter the melted metal and carbonize the weld. So it appears that it is important to get a correct mixture of gases within reasonable limits. One firm, the Davis-Bournonville Co., issue full instructions about their flame, which are here quoted as they will apply with slight variations to other oxy-acetylene systems.

"When ready to use the torch, open the valve in the oxygen tank *very slowly* until the full pressure in the tank is registered on the larger indicator. It the full pressure of the oxygen tank is turned on suddenly the oxygen regulator may be damaged and its efficiency will be ultimately impaired by such method. Then open the valve in the regulator

slowly until the pressure indicated by the smaller indicator registers the desired working pressure for the thickness of metal to be welded, as shown in the printed table. The working pressure, as shown by the smaller indicator, should always be increased from 0 to the desired pressure, instead of being turned on at high pressure and reduced. A low pressure regulator (having indicators registering only 500 pounds) should never be used on high pressure oxygen cylinders.

Now open the acetylene cock in the torch, and light the acetylene. Adjust the acetylene regulator so that there is a reasonably strong flame, then open the oxygen torch-cock until the oxygen reaches the full pressure; *again* looking at the small oxygen indicator to see that it is at the pressure desired. Then increase, or reduce, the pressure of the acetylene by turning the screw in the acetylene pressure regulator, until the two cones formed by the flame unite into one small cone. No oxygen should be added after this cone is perfectly formed, as if this is done there will be an excess of oxygen. The cone should be constantly observed, and occasionally tested, which can be readily done by adding a very slight pressure to the acetylene, which will immediately indicate itself by extension at the point of the cone. An excess of oxygen will diminish the size of the perfect white cone. When the cone is properly formed, it will be neutral, and will not burn or carburet the metal (Fig. 69).

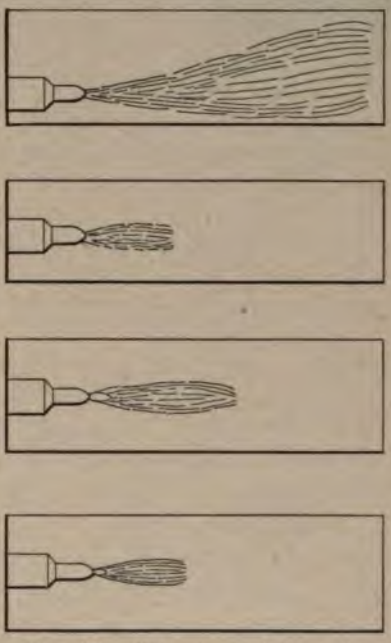

FIG. 69.—The oxy-acetylene blowpipe flame: 1. Acetylene in air; 2. excess acetylene, double cone; 3. correct flame; 4. excess oxygen. (Whittemore, Ill. Eng. Exp. Sta., Bull. 45.)

"In operation, the point of the white cone should touch the metal which is being welded, care being taken to hold the torch steadily, as actually touching the point of the torch to the metal may cause a flash-back. In such case, the gases should be turned off momentarily, and they will readily relight on bringing them again in contact with the hot weld.

"The table will give the oxygen pressures best adapted for the tip in use, and they should be carefully studied, and frequently referred to,

until the operator becomes familiar with the same. Both the oxygen and the acetylene gases should always be turned off at the service pipe, and at the oxygen cylinder, when welding is discontinued."

Beginners should commence by welding thin strips of iron or steel 1/8" or less in thickness. These light metals can be welded without the addition of welding material. The torch should be given a rotary motion, with a slight upward and forward movement with each rotation. This will tend to blend the metal, and reduce the liability of over-heating. The practice on this light metal should be continued for a day or two, or until the operator becomes instinctively familiar with the apparatus, so that he can devote his whole attention to the welding, without an unquiet feeling as to the operation of the apparatus itself.

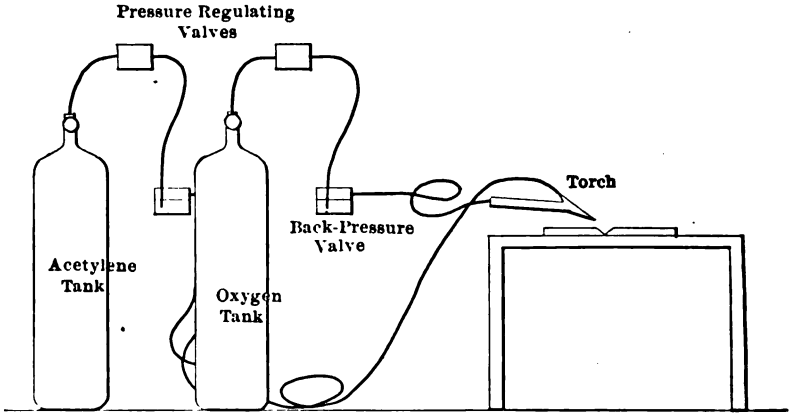

FIG. 70.—Diagram of high-pressure oxy-acetylene system, using storage tanks.

"There is a strong tendency with beginners to experiment with various kinds and thicknesses of metal, but they will become efficient far more quickly by mastering one kind of weld, before undertaking another."

Expansion and Contraction.—All of the weldable metals and alloys expand as they are heated. The coefficient of expansion is slight for each degree of heat, but multiplied by many hundred degrees it becomes a troublesome factor in cast metals and all brittle alloys. Expansion and contraction is especially troublesome in large castings having both thin and thick parts. The only way to weld such pieces or to weld any pieces which will

be apt to crack from the welding heat or from internal strains that arise on cooling, is to preheat the pieces, and to cool it very slowly and carefully after welding. This is true of all welding processes. Thus to weld a broken locomotive-wheel spoke it is necessary to preheat the other spokes of the segment so that they will have extended equally with the broken spoke as newly welded. This is just as necessary for much smaller jobs. Preheating is also necessary for brass, copper, aluminum and alloys which by their high heat conductivity cool the part to be welded so fast that welding is difficult. Metals like malleable iron do not need to be preheated, because their tough, fibrous structure easily takes up heating and cooling strains. However, the heat of welding converts rolled brass and certain malleable irons to the cast metal in the region of the weld and this must be recognized.

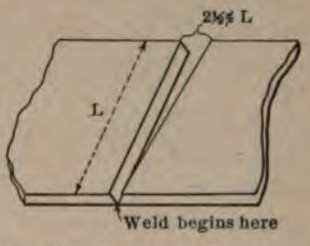

FIG. 71.—Showing adjustment of plates for welding.

Preheating is done with a specially designed oil or gasoline preheating torch or with a charcoal fire or in a gas furnace. The welder can use his ingenuity in building a temporary furnace of fire brick around his job, or covering it with asbestos or magnesia paper.

Preheating is not only very necessary in lots of cases but it saves money. It is certainly much cheaper to heat a big casting with gas at a dollar a thousand feet than with acetylene and oxygen at about twenty dollars per thousand.

Other Precautions.—It is necessary to choose the right sized tip to give the right flame for a given job. Too small a flame will waste gas because it will take it too long to melt at the weld and to catch up with the radiation, too large a flame will be quite as troublesome by melting too much at the weld and by burning the metal. Steel and aluminum are specially sensitive to too much heat, or too intense a flame.

Parts to be welded should have raw, clean edges. For instance, in steel-plate welding, the cracked or thin section may first be cut away with the cutting flame, but this leaves an oxidized edge; this oxid must be chipped off with a pneumatic chisel.

Two plates to be butt-welded together are first beveled so that there is a reentrant angle of 45 degrees at their junction (Fig. 72).

This is necessary on all plates or pieces over about 1/4 inch thickness, because it is necessary to get the flame to first melt and join the bottom or apex of the angle. Otherwise the weld may only exist in the upper portion of the joint. An ingenious method of welding steel plate is described by Spellman.[1] The beveled-edged plates are abutted and the clamps, also beveled, form a deep trough which directs the excess flame ahead of the welding cone: thus the flame becomes both a welding and a preheating flame.

In welding steel plate, the constant contraction of the welded section as the flame leaves it, tends to draw the unwelded sections together and cause them to overlap. To prevent this the plates are set diverging at a 2 1/2-degree angle ahead of the flame (Fig. 71). This gap is closed by the shrinkage just mentioned.

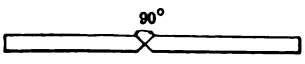

FIG. 72.—Correct bevels for strong weld.

When broken pieces, such as auto-engine crank-shafts are welded, the fracture is chipped away to the proper bevel except at several points of the fracture which are left for contacts to retain the proper alignment.

Melt bar metals and fluxes are chosen to suit the work at hand. Melt bars are either of the approximate composition of the work, or they consist of such alloys as will strengthen the weld beyond the original metals.

As with thermit welding, this is often necessary where the upset must be machined off. Thus it is expedient to use a nickel-steel melt bar for such work as auto crank-shafts. The melt bar is held close to or touching the weld. This allows it to flow into the weld as fast as it melts and before it has a chance to burn.

The fluxes and scaling powders help to keep the surfaces clean and to reduce or dissolve the oxid as fast as it is formed by the flame. Fluxes also protect such metals as high-carbon steel from having the carbon burned out; they protect copper and aluminum from unduly oxidizing; and they protect the zinc of brass, which easily burns out in a bare flame.

Cast iron welds readily. But a casting is very liable to crack either when heating or when cooling. For this reason careful preheating is necessary, and after the weld is made the

[1] *Cassier's Magazine*, December, 1912.

piece can be covered with asbestos paper and slowly allowed to cool out of reach of drafts. The melt bar is a high-silicon cast iron, low in sulphur and phosphorus. It is necessary to use a flux or scaling powder made of salt, borax, or similar chemical to take up the iron oxid formed in the flame and allow the metal to run freely. Cast iron runs freely at the weld, and for that reason vertical welding is difficult and underneath welding impossible.

Wrought iron does not melt to a fluid but becomes pasty and the metal at the weld may have to be assisted by the melt bar. If the wrought iron is not low in silicon it becomes cast iron when it cools, and even pure iron which has been melted loses its structure. This can be regained to some extent by hammering as it cools.

Steel, as its carbon content increases, becomes increasingly hard to weld. The carbon is apt to burn out; and if it does not, the steel at and near the weld loses its essential properties because its carbon has changed form. The almost infinite number of changes that take place within the range of tempering heat of steel, are very graphically described by Professor Howe in the Encyclopedia Britannica.[1] High carbon steel welds can only be restored to their original properties by after-treatment annealing.[2] There are many tricks in the welding and heat-treatment of special steels, and the welding of steel to iron, steel to copper, and welding tool steel, which need not be taken up here. Instructions are furnished by the companies, and the reader is also referred to Springer's book.

Aluminum is sensitive to oxygen to a fault, and so it is a good thing to have a slight excess of acetylene in the flame. The work to be welded is preheated, after the fracture or edges to be welded are made clean and raw. The metal does not run readily but becomes soft and may be joined by the puddling action of an iron stirring rod. The great heat conductivity of this metal, its tendency to oxidize quickly, and its low melting point, make it a difficult metal to weld. Nevertheless, it is welded successfully by good operators. The difference in toughness and ductility between cast and rolled aluminum is very great; some of this toughness can be restored by hammering the weld when hot. But the operator must bear in mind that this metal when reason-

[1] 1911 Edition.

[2] "Oxy-acetylene Torch Practice," Q. F. Springer, New York, 1911, p. 30.

ably pure is hot-short between 600° and 655° C., and may crumble or fracture under the hammer within this range.

Brass is welded with a slightly larger flame than for iron, and the cone of the flame is kept away from the work. Borax is used as a flux to prevent the metal from burning after it melts. Like wrought iron, rolled brass becomes cast metal when welded and is not so tough. Bronze calls for similar treatment.

Copper requires a large low-temperature flame, and its toughness can be restored by hammering after it is welded.

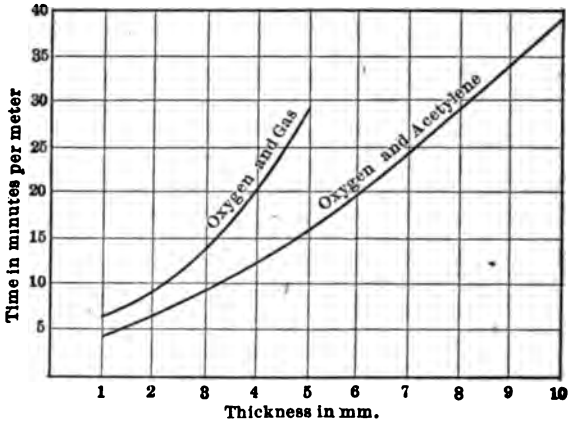

FIG. 73.—Diagram of comparative welding with gas and acetylene. (L. L. Bernier.)

Other metals and alloys are welded right along by this process. In fact the metal industry is being invaded by new alloys each of which has its own peculiarities. If one of these alloys is to be welded, the operator must know enough about it to handle it successfully. From the fact that this flame can melt practically anything, welds can be made between any two different kinds of metals which come within the range of weldability.

Adaptability.—In the early days of this process it was used and advocated for repair work only—and for small pieces at that. The fact that the flame was excessively hot (about 3000 deg. C. in the blue cone) and that the *volume* of heat was small seemed to limit it in a number of ways. For instance, a hot flame either oxidizes the metal or lays it open to oxidation; it may fracture it through expansion; it can work only on a small area at a time. But as a matter of fact this flame is used for

cutting and welding nearly all sizes of repair jobs and manufactured articles—everything from the platinum wires of an incandescent lamp up to the skeg of a ship. It is still essentially a repair system and also a wrecking instrument through its cutting torch.

Chemical and metallurgical laboratories can use the flame to advantage to get very high local heats. It is suggested that the flame may be adapted to assay work where the rock is very refractory. The cost and time needed to get a high heat in an assay furnace is often considerable. With this flame the expensive and fragile muffle might be dispensed with. At any rate the laboratory now has a tool different from the electric arc and of almost equal potency.

Typical Welds.—Probably first in importance at this writing

FIG. 74.—Repairing with the oxy-acetylene torch. (Davis-Bournonville Company.)

is the repair work this system does in machine shops, navy-yards, railroad shops, and auto repair shops. Repairs on automobiles call for an experienced operator, because these welds are on different metals and alloys. Figs. 78 and 79 suggest some of the auto repair jobs. Common among them are engine crank cases, engine cylinders, cranks, frame, springs. These parts are so designed as to require high efficiency in the utilization of the material, and therefore it is often a trick to weld without disabling the part.

Figs. 82 and 83 show the water-tube and flue-sheet of a locomotive boiler before and after welding. The plate is countersunk and the tube projects slightly. The weld begins almost at

FIG. 75.—High-pressure tank for U. S. Navy. Ends and seams welded and 3/4-in. flange welded to end. Material 1/2 in. thick, size 36×30 3/4 in. Tested to 250 lb.

FIG. 76.—Steel tubes welded to shell.

FIG. 77.—Galvanized tank with oxy-acetylene welded end piece (heat expansion would shear rivets.)

the contact of tube and sheet and as the fill-in metal flares out to a greater diameter than the tube it gives the safest kind of a weld.

The roof plates of the modern steel passenger cars are welded together. The edge of the plate is turned over to an angle of 90 degrees and the edges of the two adjoining sheets edge-welded.

Steel, brass or aluminum-alloy furniture of all sorts is welded and is far more serviceable than the riveted or soldered furniture.

One of the most common hand-welded articles is the steel-containing tank (Fig. 77). These tanks, made of high-grade

FIG. 78.—Welded cylinder, oxy-acetylene process.

sheet steel are now used for many purposes—high-pressure gas tanks, generating barrels, cylinders, range boilers, superheaters, etc.—and such cylinders are much better seamless than riveted, provided the welds are sound. Several years ago it was acknowledged that the caps could be welded on seamless tubes, but there was a feeling that these welded cylinders ought not to be trusted for high pressures. But such tubes and cylinders are now in universal use, which shows that they stand the test.

Besides the repair works already mentioned, the oxy-acetylene is used to a great extent to cut up, patch and build up corroded, cracked and leaky boilers. This kind of repair work was done in

France under government supervision long before it was trusted in this country. Boiler welding was under strict supervision and boiler welders had to serve an eight months' apprenticeship. It is doubtful if acetylene welding will replace riveting for boilers or structural iron and steel where strains are tensional. A good weld is much stronger and also quite a bit cheaper than a single-

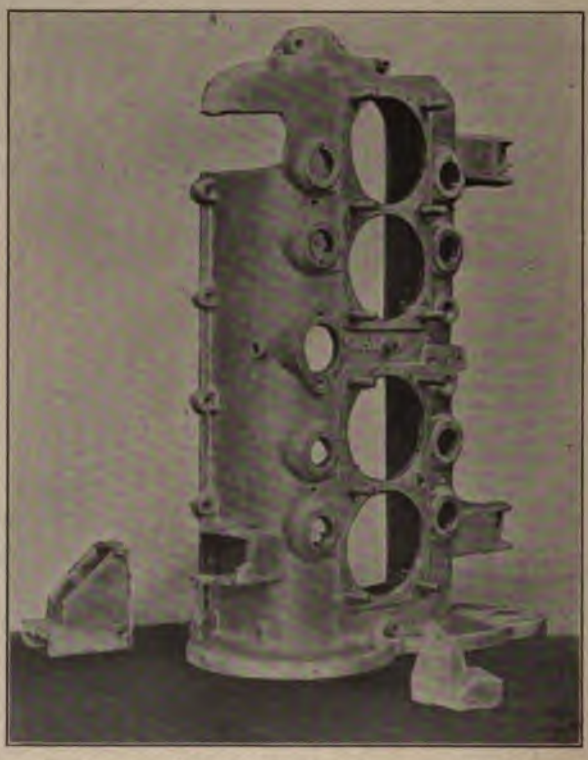

FIG. 79.—Top section of broken crank case with broken arms.

or even a double-riveted joint. But a riveted joint is of a definite known strength, and a weld may be porous and brittle, under a good smooth surface, and may be actually less than 25 per cent. strength.

Locomotive boiler welds and patches as carried on at the Nashville, Chattanooga and St. Louis R.R., at Nashville, are described as follows.[1]

[1] *Railway Age Gazette*, Aug. 5, 1910: W. G. Reyer and R. W. Clark.

"Side sheets can be successfully welded in a locomotive firebox in a comparatively short time and with very little trouble if the work is properly done. Provision must be made for contraction when the weld cools off. The cutting of the opening for the patch in the firebox should be done with a pneumatic hammer and not with the blowpipe, as in the latter case the steel will oxidize where it is cut and it will be difficult to make a successful weld. The sheet and the patch should be

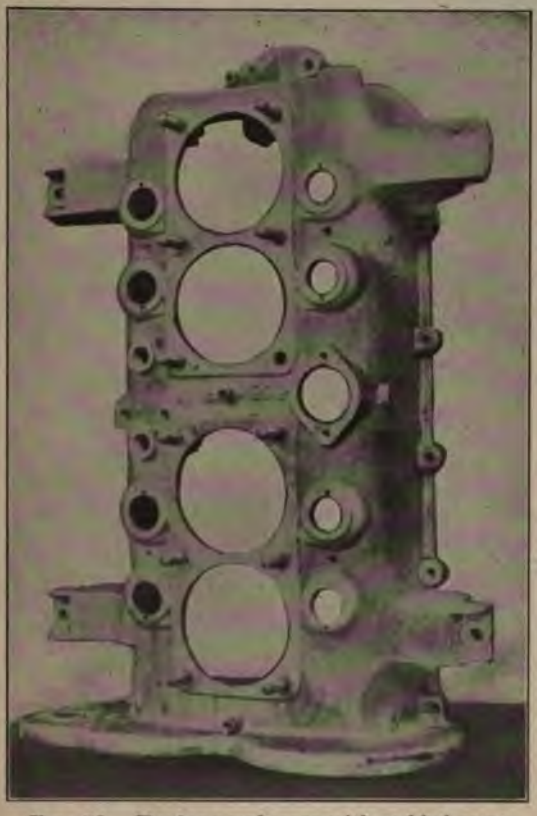

FIG. 80.—Engine crank case with welded arms.

trimmed with a bevel such that when the patch is set up ready for welding the two sharp pointed edges will touch and an opening or V will appear, leaving an angle of 45 degrees between the two edges of the sheets (Fig. 84). To allow for contraction of the patch a U should be formed near its edge, as shown in Fig. 84 and projecting on the same side as the open side of the V formed between the edges of the two sheets. This can be made on a press, or under clamps or with a fuller. On a 5/16-inch sheet, for instance, the U depression should be about 1/2

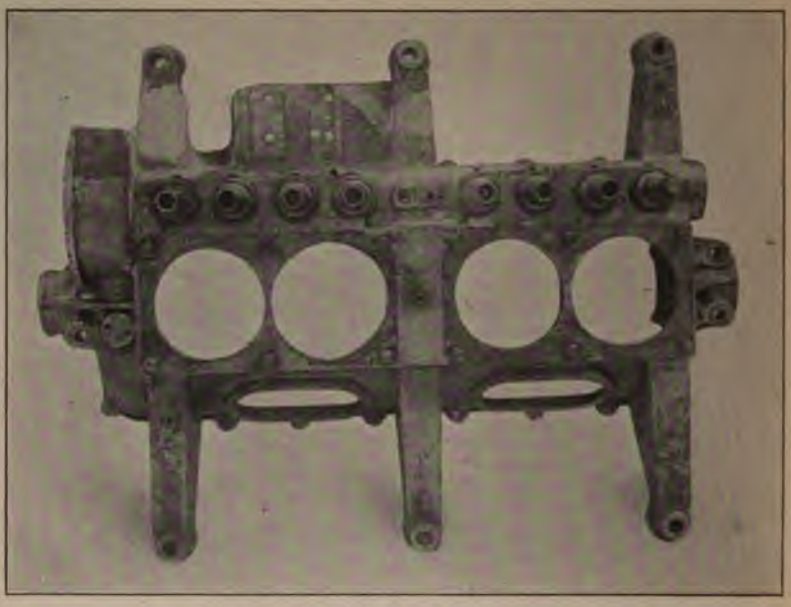

FIG. 81.—Welded aluminum engine bed.

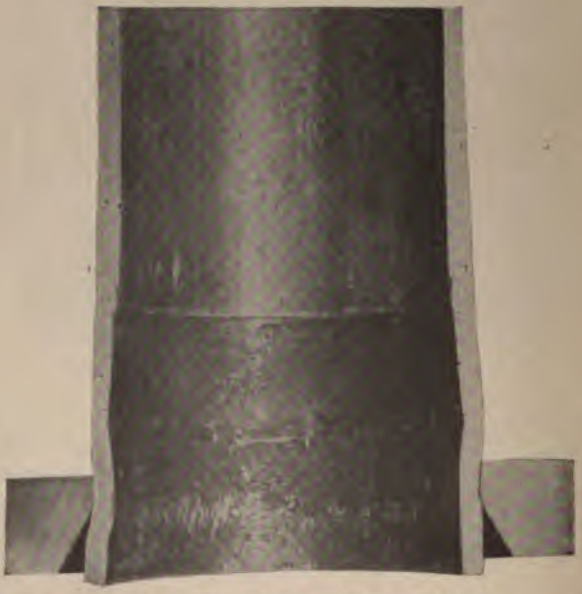

FIG. 82.—Flue of boiler before welding.

inch deep with a radius of about 1/2 inch. While the weld is cooling off the U should be hammered down with a pneumatic hammer. The U must, of course, project toward the fire side so that it may be hammered. In putting on a patch it is best to apply the staybolts before welding. Splendid results have been obtained in making a large number of welds in this way, some of them directly under the arch on high-pressure boilers.

"The welding torch should be kept clean. If too much oxygen is used the metal will oxidize and will not weld. To get a perfect weld in applying a half side sheet, form a U along the top of the sheet. In welding a fire-door flange where the sheet is cracked in the knuckle

FIG. 83.—Flue of boiler after welding. (Courtesy Oxweld Acetylene Co.)

of the flange, do not cut out any more of the door sheet than is necessary, keeping the weld as near the turn of the flange as possible, thus leaving it free to contract without putting much stress on the weld. If this cannot be done it will be necessary to use a U, as described above. It is good practice to hammer on the heel of the flange after welding.

"Cracks develop in the firebox that can be welded perfectly, and, again, there are cracks that cannot be welded satisfactorily. For instance, if a crack in the knuckle of the flange runs the long way of the flange, it can be cut with a diamond-point chisel and a good weld can be made. If the crack is around the knuckle of the flange it is useless to try to weld it, as there is no way to provide for contraction, and nine time out of ten the weld will pull apart. Where the crack is in the

center of a side sheet, we have never been able to make a successful weld;[1] the first effort to weld a crack in a side sheet caused no end of trouble; the crack extended 12 inches from one staybolt to another, taking in three staybolts. It was cut out with a diamond-point tool and apparently welded very satisfactorily; but after the weld cooled off it was found that the next row of staybolts had developed a similar crack—the contraction had pulled the sheet apart in the weakest place. The new crack was cut out and welded and after cooling a similar crack developed which opened 3/32 inch. We continued to weld one crack after another until the first weld made had broken. We tried to weld it again but found it impossible to make a successful weld because of oxidization. We cut out the bad place in the sheet and applied a patch, which proved entirely satisfactory."

Several recent welds of heavy castings show that the process is not limited to light work. Thus a 12 1/2-ton casting of a huge fly-wheel spider had a big section broken off the end of one arm when the riser was knocked off. The piece was welded on.

Another fly-wheel, 14 feet in diameter with a 4-foot face, was

FIG. 84.—Partial view of patch about to be welded to side sheet of locomotive boiler.

broken on the face for about 22 inches as the result of a fire. This wheel was also welded successfully. Of course both of these repairs represented a large saving.

A big feat in welding was done by the Davis-Bournonville Co. in the welding of a mountain pipe-line near Boulder, Colorado. This line, 9000 feet long, had a drop of 1875 feet from the mountain reservoir to the power house. The pipe-line cost $250,000 in toto, and 600 feet of it passed through rock tunnels, and most of it was well sunk in a trench.

"About 4000 feet of the lower portion of this line has what is known as 'butt strap joint'—that is, the main portions of the pipe butt together and the joints are held in place by cover plates outside and inside of the pipe joint. This 4000 feet of the line is made up of sections 21 feet in length, three pipe lengths to the section, the top cover plates being continuous over the 21-foot section, and the trouble arose where the butt straps join together in the field joints. There were 200 of these fields joint and all of them leaked. Not only was a great deal of power lost at the leaks, but the wash of the wasted water was disastrous to the pipe anchorage.

[1] No trouble of this kind is experienced with the metallic arc (see page 45).

"The actual welding required was on about 200 fields joints. These had to be uncovered and 27 of them were in rocky tunnels with but little working room. The pipe was of sheet steel varying from 1/4 inch at the upper end to 1 3/4 inches thickness at the lower end of the line where most of the welding was done. The seams of the pipe were covered by longitudinal straps outside and inside, varying from 3/8 to 1 3/4-inch thickness, according to the thickness of the pipe, and from 12 to 30 inches in width, the inside strap being the wider, as shown by the riveting in the illustrations, and these stagger riveted. The lengths of pipe were butted, the joints covered by girth straps from 4 to 8 1/2 inches wide and of thickness corresponding to the longitudinal straps. The ends of the girth straps were beveled and tipped under the longitudinal straps.

"Fig. 85 shows a joint before and after welding. The weld is from 30 to 50 inches in length, according to the width of the straps, at each of the 200 joints welded, uniting the girth straps to the

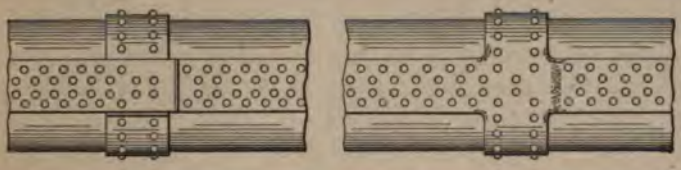

FIG. 85.—Pipe line of Central Colorado Power Co. Before and after welding.

longitudinal straps at each side, and uniting the longitudinal strap at the butt joint to the next section, so that when the work was completed there was a continuous strap without joints running lengthwise of the pipe 4000 feet, or nearly four-fifths of a mile in length. In addition to the welds, metal was filled in at each of the four corners made by the two straps, as will be seen in Fig. 85. The welds were further strengthened by 5/8-inch reinforcement of added metal.

"The work being carried on in the winter months, it was necessary to erect a small shanty to protect the workmen on the open work, and this was moved as the work advanced. As the operations were some miles from town it was also necessary that the oxygen and acetylene gas should be made as near to the work as possible, and two Davis pressure acetylene generators and a Davis oxygen plant and compressor were set up in separate camps on the mountain side. The oxygen, compressed in cylinders, was taken up the line on the construction tramway and part of the time on a stone-boat drawn by one horse, two or three cylinders at a time. The acetylene camp was moved four or five times, but the gas was piped under its own pressure as far as 500

feet from the camp. In the camp steam heat was supplied to prevent freezing of the water in the generators, which were used alternately.

A further idea of the magnitude of the work is given in the statement that 18 tons of carbide and 23 tons of chlorate of potash were used in the generation of acetylene and oxygen. The finished work was reported to be satisfactory."

Acetylene Welding versus Riveting.—The approximate strength of single-riveted boiler plate is 55 per cent.; of double-riveted, 70 per cent. L. L. Bernier, in the *Boiler Maker*, gives the ratio of cost of acetylene welding with a generator, compared with double riveting, as seven to twelve. The cost of triple riveting is not given, but it would still further increase the discrepancy. Besides being cheaper, the acetylene-weld is absolutely leak proof, a great advantage over a riveted joint.

On the other hand, an apparently sound acetylene-weld may have a tensile strength of 25 per cent. instead of 95, and may be crystalline and brittle; whereas the riveted joint is of certain strength. In the present state of the art it would be a mistake to advocate the acetylene-welding of boilers of any size, though for small containers and tubes that can be rolled and annealed the riveted and brazed joint is being rapidly superseded by the acetylene-weld. But oxy-acetylene repair welds are now frequently made on cracked and corroded boilers. Cracks are first laid open by a partial heating, until their full extent is known. Then they are welded by the flame and a melt bar, working up from the bottom of the crack. Where the plate is full of cracks or is corroded deeply, a section of the plate is cut out with a cutting flame and a fresh plate patch is welded in. Boiler repairing requires very careful preheating, hammering of the weld and subsequent annealing of the plate surrounding the weld.

Repairing Defective Castings.—One of the important possibilities of this process is in the repairing of defective castings fresh from the foundry. Even in the most careful foundry practice the scrap heap is always a very expensive mountain to the foundryman. If he can keep down the heap he can increase his profits. With the oxy-acetylene flame all kinds of defects of castings can be repaired. Broken pieces can be put together and imperfect pieces built up and repaired. As with other repair work, a preheating torch or furnace would be needed for pieces of any size, even though they were of low-carbon steel. After

the acetylene flame had done its work, an annealing furnace would be necessary. Both the oxy-acetylene process and the thermit process (see page 148) offer a solution for the economical reduction of the scrap heap.

But there is one serious limitation to the possibility of using the oxy-acetylene flame or thermit to repair a new casting. Such a casting cannot honestly be called new. The repair may make it stronger than a perfect piece, but the fact remains that it is a repaired piece. The foundryman may or may not tell his customer what he is selling him, according to his standard of honesty. It may be difficult to convince that customer that he is getting a first-class article and should pay full price for it. Many customers would not accept it under any sort of guarantee. Again, it might be equally damaging to the foundryman if it became known that he sold as perfect castings which had to be repaired, if he did so without telling the customer. Again, it is poor practice for the printer, the potter, the foundryman, etc., to accept knockdown prices for a doubtful product, and so admit its inferiority.

The fact remains that this flame offers a fairly cheap way of redeeming defective castings. The founder must use his judgment in employing it.

How to Cut Metals.—Besides its use in melting metals for welding, it has recently been found that the oxy-acetylene flame will cut through metals. The importance of this discovery is not yet realized. Wrought-iron and steel plate can be cut through as fast as a carpenter can tear through scantling with a rip-saw; cast iron not so readily. Other metals and alloys, such as aluminum, brass, etc., can also be cut. Jottrand is credited with this discovery.

Cutting is effected by both the melting and the burning of the metal. In the case of iron, the ordinary flame heats it to bright heat, when an extra oxygen cock is turned on. Iron burns with evolution of great heat in the presence of oxygen. At the same time this heat is partly transmitted to the iron in front of the jet, while the jet blows out the iron oxid and molten metal wherever it strikes. When the cutting flame is at its best it entirely oxidizes the iron, blowing out a clean narrow cut. Cutting is a spectacular process, due to the shower of slag sparks that fall from the cut.

While the cutting may be done with the oxygen flame alone,

after the iron is red-hot, modern practice uses a preheating torch to which an additional oxygen jet is attached. The torch is the ordinary medium- or low-pressure torch, while the oxygen jet is above 125 pounds. Several firms are selling such torches (see Fig. 57).

The torch is first adjusted to a welding flame, while the cock of the oxygen jet is closed. The operator points the flame at the edge of the metal to be cut. As soon as bright red heat is reached, he moves the flame inward about half an inch and turns on the full oxygen jet which strikes the edge just heated. Meanwhile the flame is heating the new part. For different thicknesses of metal he can use a given oxygen tip, of which each torch has several.

The rate of cutting varies with the thickness of the plate, and the skill of the operator. Roughly, this flame takes from 1/5 to 1/10 the time in cutting a given section of steel that two men working with a metal saw would take. While the average

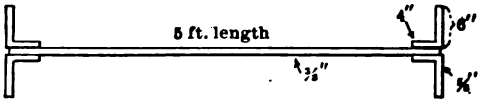

FIG. 86.—Iron girder cut by oxy-acetylene flame.

demand on the cutting flame is seldom over 6 inches, it will cut as much as 24 inches.

An exhibition of flame-cutting was given recently by M. Bournonville. During the extension work for the new New York subway approaches to the Williamsburg Bridge it was found necessary to cut through a 3/8-inch I-beam of steel, whose dimensions appear in Fig. 86. The entire cutting took 21 1/2 minutes. This gives the reader an idea of the efficiency of this process.

This flame should be used to cut any metal that resists the metal saw. Should it fail to oxidize, it would melt its way through. An oxy-acetylene cutter should be an adjunct to every repair shop of any size. It would be found invaluable in cutting away badly wrenched metal work and in cutting and working on parts of any machine, such as an automobile, where a special fixture was to be fastened. For besides its ability to cut, this flame can be made to pierce rivet holes straight through one-inch steel in less than two minutes.

This flame has found its way into the railroad repair shops, one of which uses it to cut away twisted metal on "gondola" coal cars. These cars are light, strong, and durable, and are rapidly displacing the wooden cars. But loss by wreckage is great and a bad wreck of gondolas is a very difficult thing to

FIG. 87.—Cutting up the wreck of the Battleship Maine in Havana Harbor. (Courtesy Oxweld Acetylene Company.)

handle. The cars are often shapeless masses caught together by the force of the impact, and difficult to separate. It has sometimes been necessary to clear the track with dynamite. Two storage tanks and several burners carried on the wrecking train would be of great assistance in such a wreck.

Every auto repair shop of any size will probably have one of

these oxy-acetylene outfits in a few years. The same may be said of ordinary machine shops, car shops, boiler shops, etc.

FIG. 88.—Cutting up the wrecked Quebec bridge. (Courtesy Oxweld Acetylene Company.)

The practical application of the cutting torch to wrecking is shown in the following instances:

The Madison Avenue bridge across the Harlem at New York was cut up by two torches in one week, which time included the

removal of the cut sections and the adjustment of the derrick and lighters which took care of the cut sections.[1]

The central span, 330 feet long and weighing 450 tons, was cut into seven sections. About 1500 cubic feet of oxygen and 450 cubic feet of acetylene were used at a cost of $42.00.

The wrecked interior of the burned Cincinnati Chamber of Commerce building, consisting of a twisted and tangled mass of steel girders, was removed by a two-torch outfit, working day and night. This allowed the work to be done in rapid fashion, which was necessary as six men had been buried in the ruins.

Two other notable examples of the value of the cutting torch are instanced in the cutting up of the tangled metal work of the battleship "Maine" in Havana harbor, (Fig. 87), and the wrecked Quebec bridge, (Fig. 88) with its 10,000 tons of twisted steel beams.

Costs.—Since the first edition of this book was written two factors have affected the cost of oxy-acetylene welding. The general rise in day labor cost brings up the expense, and the increased efficiency of the torch and apparatus and also of the operators brings it down. There is a great deal of difference between the amount of gas used and the quality of the weld when green or experienced men are at work. Oxygen may still be figured at about three cents a cubic foot and acetylene at about one cent but skilled labor is not satisfied with anything like thirty cents an hour.

The tables on page 98 will be helpful at arriving at the costs because they show the approximate amount of gases used.

The oxy-acetylene contractors, for some time, have had the competition of the thermit and incandescent electric (Thomson) welding processes. In a general way these processes began where oxy-acetylene left off. However, the electric arc-welding process has recently made a rapid advance and has now invaded the field of iron and steel welding, where it often comes into direct competition with oxy-acetylene.

Some of the following statements taken from trade literature will help to give an idea of costs.[2]

A Cahill vertical water-tube boiler was repaired by building up 17 tube holes, a patch welded in and a 2-inch crack closed, all in 17 hours of welding time at a total cost of $29.49.

[1] *Autogenous Welding*, April, 1911, Davis-Bournonville Co.

[2] Oxweld Acetylene Company.

A cracked locomotive driving rod was welded in an hour and a half at a total cost of $5.22.

One foundry used a cutting torch to cut off the casting risers on large castings. Besides cutting the cost to about 1.4 cents per square inch, it saved the labor of hoisting the castings to the saw.

The Minneapolis & St. Paul Traction Co. welded their copper bonds at a unit cost of about $0.25. They also obtained perfect contact with this welded bond.

The record sheet of the Frisco Shops at Springfield, Mo., gave a comparison of the oxy-acetylene repairs for a given period, (one week) over the best previous method (presumably not a special welding process). The jobs included all sorts of repairs —boilers, driving rods, spokes, links, rocker arms, cutting cab, etc. The estimated saving of time was 208 hours, or 26 8-hour days. The money saving was $216.36.

The cutting cost is only a fraction of the welding cost per foot, in spite of the fact that much more oxygen is used in the flame. Table 20 is for machine cutting only.

The cost of hand cutting steel is not so easy to get at, because conditions are seldom uniform. In hand cutting it is presumed that one-third more gas will be used and one-third less be cut per hour than is shown by the table.

The following table[1] is intended to show the costs and efficiency of the three principal welding flames. Costs are figured on the basis of generator acetylene one cent a foot; compressed acetylene, two and one-half cents; oxygen, three cents; hydrogen, one cent; coal gas, one and one-quarter cents. I have reduced the estimated temperatures to reasonable limits.

Chemistry and Thermics.—A definite formula should not be laid down for the oxy-acetylene flame as used. This for the reason that the products of combustion vary with different proportions of the gases and in different parts of the flame. Lewes[2] gives the probable maximum of the flame as lying between 3100 deg. Cent. and 4000 deg. Cent. This forbids the formula of Davy,

$$2C_2H_2+5O_2=2H_2O+4CO_2,$$

because water is dissociated at only 780 deg. Cent. Beltzer makes it

$$C_2H_2+O_2=2CO+H_2,$$

[1] *Bulletin Technologique*, Sept., 1907.

[2] "Acetylene," Vivian Lewes, 1900, p. 120.

TABLE 25

	Oxy-acetylene mixture	Oxy-hydrogen mixture	Oxy-coal gas mixture
Number of B. T. U. obtained by complete combustion of one cubic foot of gas.....	1570	290	616
Temperature (Fahr.) obtained by combustion of the mixture (approx.).....	3000° C.	2000° C.	1700° C.
Cubic feet of oxygen required to burn one cubic foot of gas to obtain the best welding flame (from practical tests made).....	1.30[2] 1.70[3]	0.25	0.67
Cubic feet of oxygen required to obtain 1000 B. T. U. with a welding flame.....	0.765[2] 1.00[3]	0.86	1.09
Cubic feet of heat-producing gas required to obtain 1000 B. T. U. with a welding flame.....	0.59	3.44	1.63
Cost of 1000 B. T. U. (cents)	2.89[1] 3.59[2] (generator acetylene) 3.78[1] 4.39[2] (dissolved acetylene)	5.92	4.20

while Beaupré allows less than one part monoxid in 100,000 of the residual gas.[3] Presuming that none of the carbon forms monoxid, Beaupré states that oxids of nitrogen are formed in small quantity and ozone in very appreciable amount. Le Chatelier[4] gives hydrogen, carbon dioxid, and monoxid as the principal gases from burning 7.74–17.37 parts acetylene in 100 parts air. It is quite likely that the layer of hydrogen on the outer surface of the flame is partly burned to water, and partly dissipated.

Theoretically, the acetylene requires about 2.5 parts of oxygen. But practice proves that this gives an oxidizing flame.

[1] Medium-pressure torch used.
[2] Low-pressure torch used.
[3] *Comptes rendu.*, 1906, 142, 165–6.
[4] *Comptes rendu.*, 121, 1144.

So the proportion of 1 part acetylene to 1.50 oxygen is recommended. Recently M. Bournonville's experiments have shown that, with his torch in working order and the flame the proper color and shape, the proportion fell as low as 1 of acetylene to 1.28 oxygen.[1] One torch uses only 1.14 oxygen. However, this seems a small matter. The flame should be decidedly reducing, but should not be so charged with excess acetylene that it will deposit carbon.

The temperature commonly ascribed to the oxy-acetylene flame is 3500 deg. Cent. Acetylene is composed of 92.3 parts carbon and 7.7 hydrogen, according to its symbol. Its temperature of dissociation is 780 deg. Cent., according to Lewes;[2] on burning, its heat value is 310,500 cal., according to Thomsen.[3] This great heat need not all be attributed to the burning of nascent carbon, for the gas is endothermic, requiring 47,700 cal. for its formation.[4]

Le Chatelier[5] gives formulas of reaction and temperatures for three different mixtures of acetylene with air, and shows that a minimum of air produces carbon dioxid and water; and an excess of air, carbon monoxid and hydrogen. In any case, the flame if properly handled is reducing beyond the blue cone, which should never be allowed to more than touch the work in hand. Such hydrogen as remains unburned in the flame is claimed to form a protecting envelope.

Testing.—It is natural to expect that a unit cross-section of an oxy-acetylene weld will not be of equal strength with the metal before welding. The metal has been melted, perhaps oxidized or carbonized slightly, and has cooled quickly. If the weld is not pounded or worked while cooling, the chances are that the metal has crystallized and is brittle. The average oxy-acetylene weld is more brittle than the metal itself, and has from 60 to 95 per cent. of the tensile strength. To make a weld as strong as the unwelded metal, an upset or extra thickness of metal must be added to the weld. Some writers make the ridiculous statement that the weld is even stronger than the original metal. This is only possible when a large joint is made. And in any

[1] Special information.
[2] "Acetylene," Vivian Lewes, 1900.
[3] *Thermochem. Unters.*, 4, 74.
[4] Roscoe and Schorlemmer, Vol. I, p. 770. "Treatise on Chemistry."
[5] *Comptes rendu*, 121, 1144.

event the elasticity is much reduced even when the joint has been hammered or pressed.

Whittemore,[1] who made accurate and exhaustive tests of oxy-acetylene welds, states that too much stress is laid on preheating and hammering, as well as on very careful flame regulation, but he found that forging added about 10 per cent. efficiency to the weld. He adds that 100 per cent. strength is out of the question, 85 per cent. being about as high as can be expected if the weld is as thick as the plate.

THE OXY-HYDROGEN PROCESS

General.—The oxy-hydrogen flame is the first, historically, of the high-temperature flames. It was used long before the discovery of industrial electrolysis of water or the production of oxygen by liquid-air process. The first fiames were fed with *oxygen* generated from potassium chlorate and manganese dioxid or from the decomposition of sodium and potassium peroxids with water or similar methods, and with *hydrogen* from zinc and hydrochloric acid or similar methods. Both the hydrogen and the oxygen can be used independently for the following combinations, the hottest first:

1. Oxy-hydrogen.
2. Oxygen-coal gas.
3. Air-hydrogen.

Apparatus —The first efficient apparatus was devised by Newman,[2] who used pure oxy-hydrogen (detonating gas) under 2 or 3 atmospheres' pressure. The burner was a glass tube about 4 inches long, of 1/80-inch bore. The flame was kept at the tip by reason of the pressure and the narrow bore. In 1847, Robert Hare, of Philadelphia, fused 2 pounds of platinum with a blowpipe of his own invention. He also used detonating gas; and as a safety device, to prevent back-fire explosion, a handle packed tight with copper rods, through which the gas was forced to the tip. This acted on the principle of the Davy lamp. In 1859 Deville and Debray revived this flame for platinum welding, and since then it has been employed in working that metal and also, sometimes, for gold and silver.

At the present time the oxy-hydrogen flame is much used in laboratories for production of high heat and to a limited extent

[1] *Illinois Bulletin* 45, Engineering Experiment Station; September, 1910.
[2] Encyclopedia Britannica, Vol. XVIII, p. 105.

in repair and boiler shops. It has long been the preferred method for sealing lead chambers for sulphuric acid manufacture by the contact process. Before the advent of the electric arc, bright light was obtained by heating a chunk of lime in this flame. This once widely advertised light is almost unknown at present. Before industrial oxygen and hydrogen were made by electrolysis of water, this flame was quite expensive, and recently it has been crowded severely by the oxy-acetylene process. But in platinum welding, lead soldering, and laboratory research it holds its own.

Detonating gas[1] is made by the decomposition of water without separating the resultant gases. It can be used for soldering and welding, provided the burner is protected from back-fire, by passing the gas through a safety chamber filled with fine porous material or guarded by a water valve. Detonating gas is com-

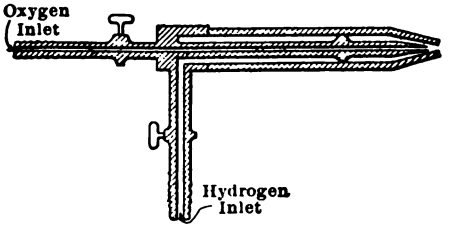

FIG. 89.—Oxy-hydrogen blowpipe.

paratively cheap, though the railroads often object to handling it. Separate oxygen and hydrogen are to be preferred on account of safety.

The outfit consists of tanks of the gases, tubes, and a burner (see Fig. 89). To prevent one gas from flowing into the other gas supply tank, if the pressure of the second gas should fail, each leading tube is provided with a safety water valve. The burner is a tube in a tube; the inner tube carrying oxygen, the surrounding tube hydrogen. Both have cocks. The hydrogen is first turned on and lighted; then turn on the oxygen. This burner is also suited for oxygen-coal gas.

Fig. 90 shows the air-hydrogen torch; the hydrogen is injected at the handle and draws in air through holes in the tip. The amount of air is regulated by a ring. This burner resembles the Bunsen burner, and is used for small work, where great heat is not needed. The hydrogen may be produced by the zinc-acid process.

[1] See page 105.

M. U. Schoop,[1] the welding expert, recommends the burner shown in Fig. 91 for large-scale work. The torch has two chambers. The first is filled with oxygen. The hydrogen tube passes through this chamber into the second. The injected hydrogen draws oxygen from the first chamber into the second, where they mix before coming out at the nozzle. This torch is liable to back-fire, but it gives a perfect combustion and prevents free oxygen in the flame.

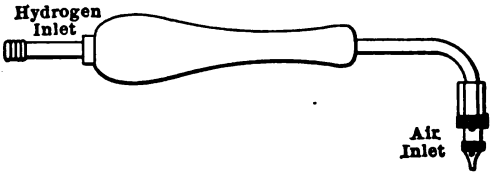

FIG. 90.—Hydrogen-air blowpipe.

The air-hydrogen process is apparently cheaper, but when it is considered that much less heat is evolved and that three hours' time are needed to one hour for oxy-hydrogen, it turns out to be dearer. Schoop claims that it is more dangerous than oxy-hydrogen. It is the preferred flame for "lead burning," as the sealing of lead seams is called. C. H. Fay[2] has explained the apparatus and process in great detail. He used apparatus of the Kirkwood & Herr Hydrogen Machine Company, of Chicago.

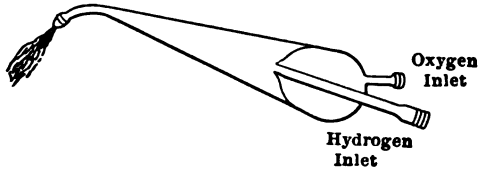

FIG. 91.—Oxy-hydrogen burner allowing perfect mixing of the gases.

It included: an air gasometer; a hydrogen-generating apparatus, using zinc and sulphuric acid; and a regular burner with two cocks. If the hydrogen was used under pressure up to 30 pounds, the air gasometer could be done away with, and air introduced by injection instead.

The Flame.—Oxygen and hydrogen for combustion are mixed in a long-shanked burner at the lower end of the handle. They

[1] *Electrochemical and Metallurgical Industry*, July, 1905.
[2] "Lead Burning," 1915.

burn at the tip with a pale blue, almost colorless flame. The theoretical formula of combustion is

$$2H_2+O_2=2H_2O.$$

Though these gases will unite as low as 155 deg. Cent.,[1] the action is slow. Explosive ignition of mixtures of the gases in different proportions occurs at an average temperature of 825 deg. Cent. Richards[2] gives the temperature of the hottest part of the flame as 3191 deg. Cent., and of the air-hydrogen flame as 2010[3] deg. Cent. Bunsen's experiments gave a maximum of 2844 deg. Cent. The former temperature, of course, is not to be found throughout the flame, if at all. The actual temperature is probably not much above 2000 deg. Cent. under working conditions, and while this is above the fusion point of most of the metals, it is none too high when conduction is reckoned on. The heating value of the hydrogen flame is much less than the acetylene, being 67,940 calories.

Practice.—In using the oxy-hydrogen flame it is necessary to use an excess of hydrogen over the theoretical amount of two volumes to one of oxygen. Otherwise there is danger of oxidizing the metal surface with hot oxygen. Platinum is the exception. This metal absorbs hydrogen and swells up. When cooling, it occludes the gas and becomes rough and pocked. One writer[2] recommends 4 to 5 volumes of hydrogen to 1 of oxygen for ordinary welding. This is so in the case of iron, copper, aluminium, and other oxidizable metals, when the unmixed-gas type of burner is used. But no such excess is necessary where the gases are mixed before ignition.

In lighting the oxy-hydrogen burner, turn on two-thirds of the hydrogen first and light it, then turn on oxygen until you have a pale blue conical flame. Then turn the hydrogen on full. If the burner is of the type shown in Fig. 91, do not light for at least ten seconds; and turn the oxygen off first when extinguishing.

The air-hydrogen flame, being cooler, must be larger. Hydrogen is turned on and lighted first. The flame will be about 3 inches long, pale red, and will burn unsteadily. Now turn on air until the flame shortens to 2 inches and has a fixed, pale blue

[1] Roscoe and Schorlemmer, Vol. I, p. 287, "Treatise on Chemistry."
[2] *Electrochemical and Metallurgical Industry*, May, 1905.
[3] *Electrochemical and Metallurgical Industry*, May, 1909.

cone. If you are using an injector air-burner, you regulate the air by turning the air ring.

In using either flame do not bring the end of the cone of oxygen against the work in hand. If you do, you are liable to burn your metal.

The operator is advised to use a flame of such size that it will not melt the metal at once. Slow melting will make a better job, and the metal will not be so apt to run away from the joint

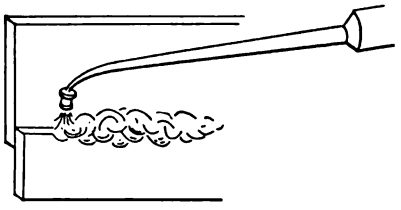

FIG. 92.—Lap welding lead sheets with air-hydrogen flame.

before he is prepared for it. Operators commonly weld a drop at a time as shown in Fig. 92. They then go back over the seam a second time to smooth off the surface.

Different metals require different treatment. There are little points in the handling of this flame that the operator will have to work out for himself. Like any highly efficient tool, it requires a skilled workman.

"The time[1] for welding 1 meter of sheet iron 3 mm. in thickness is about 15 minutes, while for welding 1 meter of sheet metal of 0.5 mm. thickness, it is from 4 to 6 minutes."

[1] *Electrochemical and Metallurgical Industry*, F. C. Perkins, May, 1906.

PART IV

THERMIT

The Thermit Process

General.—One of the most recent and successful methods of welding is called the Thermit Process. It was invented by Dr. Goldschmidt, of Essen, Germany, and is exploited by the company bearing his name. In this process a mixture of aluminum and oxid of iron is ignited. The aluminum reduces the iron from its oxid, and evolves an intense heat, about 2500 deg. Cent., or twice the temperature of molten steel. This molten steel, called thermit steel, is then poured around the metal to be welded and forms a melt-joint that is very strong when cold. Its present application is entirely in repairs of large metal pieces and in making continuous welded railroad track. It is used in repair shops for mending car axles, auto and electric motor cases, broken and defective castings, broken parts of reciprocating engines, broken rudder-posts, skegs, and sternposts of ships, and for repair work in general along this line. Special thermit mixtures are being advocated for toning up the melted steel in the ladle in foundry practice, for preventing "piping" of ingots; and the company is using the strong reducing property of aluminum in reducing a number of the less used metals, such as tungsten, chromium, and boron, to a pure metallic state.

Thermit is first of all a welding process. Its good and weak points may be summed up thus:

1. Simplicity of the apparatus.
2. No special skill needed to do the work.
3. Possibility of repairing breaks difficult of access and of repairing parts *in situ* that would otherwise have to be taken out.
4. Possibility of intense local heating of large parts.
5. Time and money saved in most repair work.
6. Possibility of varying the chemical composition of thermit steel so that its properties may be varied.

7. It is at present limited to rail welding and repair work.

8. Only iron and steel can be welded.

9. The cost, though much lower than the forge method of welding, is still often prohibitive.

The process is used by many of the leading railroads, shipyards, and machine shops, both for repair work and for special jointing, such as that of the third rail of the Paris subway. At present Dr. Goldschmidt is trying to produce chemically pure metals on a commercial scale. He has met with success in reducing metallic manganese, chromium, tungsten, vanadium, molybdenum, boron, etc., from their ores and oxids. This new field in metallurgy, now called aluminothermics, seems to promise as many new and interesting possibilities on its horizon as did the experiments of Moissan with his electric furnace.

The fundamental idea beneath thermit has been in the minds of metallurgists for at least a half-century. In the year 1869, a Mr. Budd[1] describes a process for reducing the alloyed silicon in pig iron. His idea was to burn it out with hematite ore, the formula being:

$$3Si+2Fe_2O_3=4Fe+3SiO_2.$$

He made a paste of hematite and smeared it over the bottoms of the pig molds. The molten iron, which appears to have been much too high in silicon, was run into the molds, and immediately the silicon began to burn out of the iron, first taking up the oxygen of the hematite mud on the bottom of the mold, and then uniting with some of the iron and coming to the top as a silicate-of-iron slag. Most of the iron reduced from the hematite added itself to the pig. Like the Goldschmidt method, this was the reduction of one metal by the transfer of its oxygen to another metal.

The fact that aluminum has the greatest affinity for oxygen has long suggested it as a final reducing agent. And its steady fall in price since its discovery by Woehler in 1857 finally brought it, about 1895, within range of the market. Woehler himself tried to smelt chromium from its chlorid by ignition with metallic aluminum. After an explosively violent reaction, he found he had an alloy of chromium with aluminum.

[1] *Transactions of the Iron and Steel Institute*, 1869; "On a New Process for Removing Silicon from Pig Iron."

A number of later attempts were made to use aluminum as an agent for reducing the rare metals from their oxids. Yet, though it had an intense affinity for oxygen, the combustion was hard to start, and when started was hard to control. Experimenters mixed it as a powder with a metallic oxid and heated the mixture from the outside. Finely divided metallic aluminum will not burn at the temperature of molten cast iron. So that when the contents of the crucible began to react, the initial temperature was already so high that the reaction was an explosion. Dr. Goldschmidt overcame this by setting off the cold powder with a fuse of barium peroxid, BaO, which in turn was set off by a storm match. A charge of several pounds was found to burn in less than 30 seconds, and the temperature of the mass rose to an approximate 2500 deg. Cent. Larger quantities, though starting to burn from a cold and coarsely powdered sand, often boiled over. A premixture of cold steel turnings remedied this. The result of the burning was an intensely hot iron whose composition could be varied at will.

The commercial value of this invention is obvious. There are many processes and many emergencies where a very hot molten iron is invaluable, yet where it is difficult and expensive to get this heat by any known means. Take the case of a broken casting of some large machine that would in the ordinary course of repair have to be taken apart and shipped to the nearest forge to be welded. If, however, a definite quantity of iron, heated to twice its melting point, can be made on the spot, it can be poured around this break without dismantling the machine. It will then form a welded union, much as though one were to put the butts of two candles together and pour hot tallow over the joint. The tallow would melt into the candles before it itself cooled, and join the two with a homogeneous substance.

In order that the mechanical aspect of the thermit weld may be clear to the reader, a simple case of rail welding will be outlined. After which the appliances used in the process will be described in detail.

Apparatus and Rail Welding.—Suppose a case of two rails abutting which are to be welded together. It is a railway crossing where heavy trains pound. The weld must be at least as strong as the rail. It must be so made as not to interfere with the travel of the wheels by coming up over the head of the rail. First of all, the rail ends must be cleaned of oxid and grease with a sand

or emery-paper or hydrochloric acid. The rails are laid a space of three-fourths of an inch between them and then :en the heads of the rails is placed a steel insert cut from :eel. A mold made of two pieces (Fig. 99) is then clamped :her side of the rail junction. The shape of the interior of molds depends of course on the shape of the rails and on iape of the collar to be cast around them. The mold has a ng gate and a riser gate placed at the top and on either)f the rail top; also a preheating gate at the bottom. A :ne compressed-air preheating torch is directed into the ating gate and the rail ends in the mold heated to a good eat. This is done so that the first part of the thermit n will not freeze when poured on the rails, nor form blow in the weld.

have then two rails enclosed in a mold whose capacity, he rails themselves, is known. To produce enough thermit to well fill this mold and to allow as much more to fill the

93.—Rails before welding.

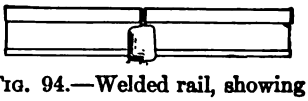

FIG. 94.—Welded rail, showing thermit-steel shoulder.

r and the *riser, take eighteen times as many ounces of thermit r as there are cubic inches of surplus space in the mold.*

: above amount is arrived at as follows: One cubic inch el weighs 4 1/2 ounces. Four and one-half ounces steel is ced by twice as much thermit powder by weight, or nine s. And as the runner and riser take as much fluid as the : of the mold, we multiply again by 2 and get *eighteen.*

wever, it is customary, unless using the special thermit n as *railroad thermit,* to add manganese, nickel and steel iings (see page 162), in which case about one-sixth less iit is taken.

en a *wax collar* is first built on the joint, the amount of iit should be *thirty times* the weight of the wax used. The t of the wax used is found by subtracting the weight of iece of wax remaining from the total weight of the original ump.

: proper amount of thermit powder is poured into the cone)le (Fig. 98), and a spoonful of barium hydroxid is heaped the thermit. The crucible is placed with its tap hole about

4 inches above and directly over the pouring gate in the mold. Set off the barium powder with a storm match and get away as soon as the barium is caught. The burning quickly spreads from the barium fuse to the thermit, and in a fraction of a minute the entire contents of the crucible are boiling at a temperature of about 2500 deg. Cent. White smoke, flames, and drops of white hot slag are ejected during the combustion, which is most spectacular and reminds one of the blowing of a Bessemer converter. In working with thermit it is well to wear smoked glasses, as the glare of the reaction and the hot fluid is troublesome. In about thirty seconds the reaction is completed, but the crucible should be allowed to stand for a half-minute longer to enable the slag to

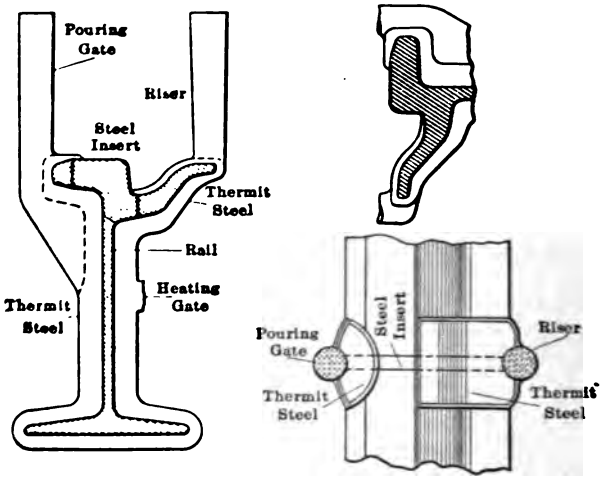

FIG. 95.—Sections of improved thermit weld for rails.

rise to the surface. It is probably for the reason that the slag does not have time to rise before the workman taps his crucible that the joints sometimes show blow holes and faulty structure. About a minute after lighting the fuse, the workman knocks the stopper out of the bottom of the crucible, and the white-hot metal pours out into the mold. As the stream enters the mold from below (Fig. 100) it heats the ends of the rails and passes on up and out into the riser. The last of the metal stream remains in the mold, and as it is very much hotter than the melting point of steel, it eats into the sides of the rails and knits fast on cooling. The joint should remain undisturbed for at least five minutes to allow

the metal to harden. It may then be treated in a number of ways—either allowed to cool slowly in the mold, in which case the joint will be composed of soft, tough steel, or quenched in oil from a red heat, in which case the joint will be very hard, and perhaps brittle. Fig. 95 shows sections of this improved weld.

This is one of the principal applications for the thermit welding process as street railway companies find it necessary nowadays to bond their rails permanently not only mechanically but electrically. A thermit weld between rail ends increases the life of the rails, gives a permanent electrical and mechanical bond which will not deteriorate with time, decreases the electrical resistance of the return circuit and prevents damage of electrolysis due to stray electric currents.

Up to a year or so ago, it was the practice to weld the entire rail sections together by pouring thermit steel into a mold surrounding the rail ends, the rails being first preheated to a red heat by means of a gas preheater. This gave a satisfactory joint, but it was found necessary to do considerable experimental work in each case so as to have the thermit steel of the same composition and wearing quality as the steel of the rails. In many cases it was extremely difficult if not impossible to do this as in most cities a great many different sections of rail are used and frequently rails of entirely different composition have to be welded together. To overcome this the steel dutchman is inserted in the rail head as just described, instead of bringing thermit steel over the rail head.

If the mold is left on the rail, the heat is retained longer at the weld and the weld becomes in a measure self annealed. However, it is a fact that the welds are several times as strong as the demand upon them. There still remain to cut off the riser and pouring gate casts with a hot flame such as the oxy-acetylene, after which the joint is ready for service.

In such countries as around Los Angeles, or in such places as subways where the daily and annual temperature variation is slight it is only necessary to weld the base and the shank of the rail to give the strength needed. However, even in an equable climate like Los Angeles the rail must be buried to the head in the pavement or the highway, or a hot, direct sun will tear up the track with "Sun Snakes." In a number of foreign countries where a low-carbon steelrail is used, the practice is quite different in welding.

In case the weld comes up against the tread, the upset is ground down to the running level.

The Clark Joint.—This is an interesting and practical variation of the solid rail weld. It was devised by C. H. Clark, chief engineer of the Cleveland Railway Company. As noticed in the illustration (Fig. 96) splice bars are used at the joint. Instead of being bolted they are riveted by means of a pneumatic

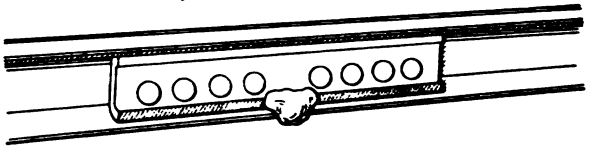

FIG. 96.—Completed Clark joint.

riveter swung from a flat car. The thermit weld is a small slice which binds the lower portion of the rails at the joint with the splice bars. In this way a rigid joint with perfect conductivity is obtained and the head of the rail is well supported.

The compromise joint is another form of rail joint which is a great nuisance both to make and to keep in alignment, unless it is welded. Fig. 97 shows a thermit weld of a compromise joint.

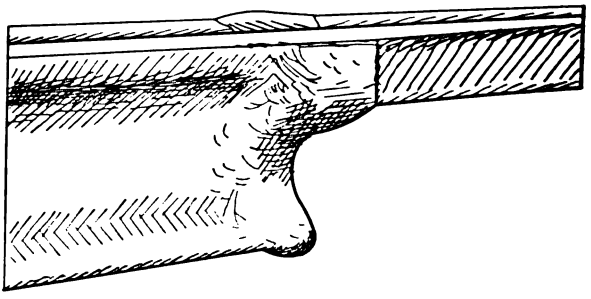

FIG. 97.—Welded compromise joint between 2 1/2-in. stringer rail and 7-in. Trilby rail.

The Crucible.—With the exception of butt-welding, where a flat-bottom crucible is used, the crucible for all thermit-welding is a cone-shaped affair that taps at the bottom. It is an evolution of the thermit process, and is so designed that the molten iron can be drawn off before the slag (Fig. 98).

It is in the shape of an inverted cone, having a rounded iron top which is clapped on as soon as the charge is fired to prevent

spattering and loss of heat. The crucible is tapped through a hole in the bottom. It is supported on a tripod or can be slung from a crane or overhead arm.

The body is of pressed steel, lined with several inches of magnesia. Magnesia is slightly more refractory than silica and it has the advantage that it will not unite so readily with the molten steel. Hence the steel remains basic.

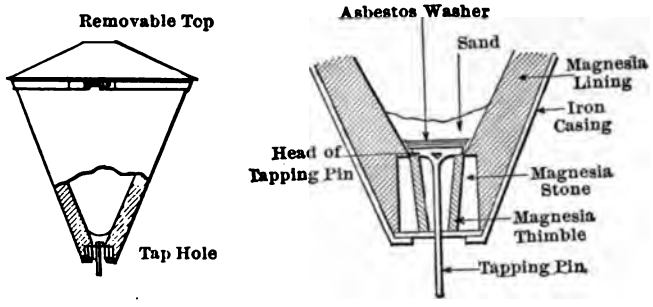

FIG. 98.—Thermit crucible with detail of lap hole.

The tap hole is the vital part of the crucible. It must remain fluid-tight until tapped, and must then withstand the rush of molten steel under pressure. As shown in Fig. 95, the bottom of the crucible holds a large cylindrical magnesia stone which has been placed in position before the magnesia lining has been tamped in. Resting inside the stone is another conical-shaped

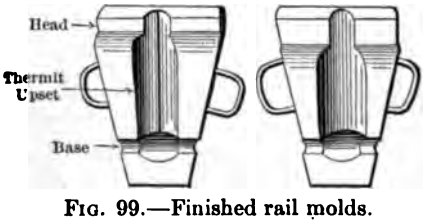

FIG. 99.—Finished rail molds.

magnesia stone, called the "thimble." It is also hollow, and its core is the channel for the molten steel. An iron tapping pin, having a long shank and a flat head, is dropped into the hole in the thimble; its head acts as a plug to the channel. An asbestos washer is dropped on the head of the tapping pin, then an iron washer, and next an inch of slag sand is poured on the iron washer. This makes a plug to the crucible that is fluid-tight for

at least a minute, long enough for the reaction to take place. This plug is tapped by driving the pin up from the outside by hitting it with a spade. The fluid rushes out and melts the tapping pin as it goes.

A new tapping pin is needed with each reaction; a new thimble

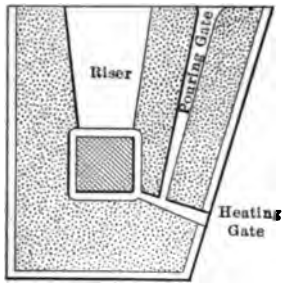

FIG. 100.—Cross-section through the latest type of mold.

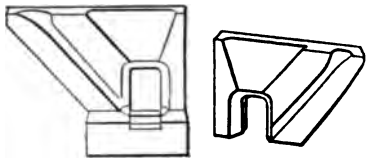

FIG. 101.—Mold partially assembled.

every two or three reactions; a new crucible lining every sixteen to twenty reactions.

The lining of the crucible is a mixture of tar and magnesia, which is tamped in between the crucible steel and an iron matrix.

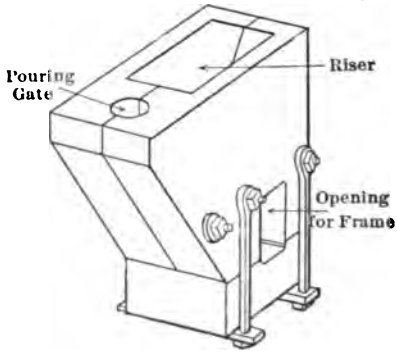

FIG. 102.—Assembled thermit mold.

When lined, the crucible is baked at a red heat for six hours, when the lining becomes hard. Even such a substance as magnesia melts away under the heat of the thermit reaction, and after several melts the interior resembles the walls of a Bessemer crucible.

The Mold.—Molds for thermit work are adapted to the particular joint to be made (Figs. 100–102). For welding a number of joints of uniform size the company furnishes patterns with which the operator can make his own molds, or else the company will furnish the molds themselves. These molds are usually made with facing material consisting of one part fire clay, one part of ground fire brick and one part of fire sand. This is for the part that comes in contact with the thermit steel. The balance of the mold is rammed up with a mixture of one part fire clay to five parts of good sharp fire sand. The company no longer recommends the use of sand-and-flour molds or of fire-brick molds. No mold can be used for more than one weld.

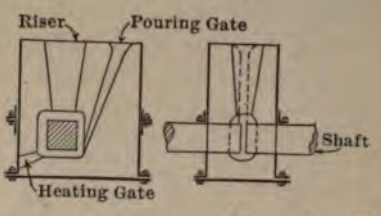

FIG. 103.—Sectional view of mold.

Until recently the company issued instructions for making molds which called for coarse white sand and fire clay in equal proportions. Cheap rye or wheat flour, proportion of 1 to 15, was the binder used. The sand and flour were mixed dry and then moistened to a stiff mass. Where an extra strong mold was needed the operator could mix in a spoonful of turpentine. However, the company no longer recommends flour for molds, nor is it advisable to use the foundryman's occasional expedients, such as molasses, clay, pitch, etc., for two reasons: The binder is subject to the great heat of the molten thermit. The more binder used, the greater space will be left when it burns out, and the mold is unreliable. Also, if binder is used, its rapid burning will generate excessive gases which may burst the mold, or injure the composition and texture of the steel joint.

For the welding of *joints similar to rails*, the molds used will vary in shape, but have the same composition. The operator can carve his own patterns out of wood.

For *butt-welding* of pipes not exceeding a diameter of 1 1/2 inches and of solid rods not exceeding 4 square inches cross-section, an *iron mold* is preferable because it is solid and easy to handle (see Fig. 107).

For *welding* larger breaks, such as fractured *locomotive frames*, the fire-clay, or fire-brick, mold is recommended. In this case the cross-section to be welded may range from 2 by 3 to 5 by 6

inches. An iron mold would absorb the heat too rapidly. The thermit collar would chill prematurely, and the mold itself would probably crack or melt, being cast iron. While a soft sand mold would probably crumble. The company furnishes a hard-baked, fire-brick mold, which is strong and refractory, at the same time being a fair non-conductor (Figs. 101 and 102).

It often happens, in thermit repair work, that the fracture to be mended is of a peculiar shape. The operator will be at a disadvantage in making his patterns, as the fracture is not only irregular, but the shape of the piece prevents measurements for a mold being taken. In this case the operator builds up a collar of cerecine wax of the size and shape that he intends for the finished welded collar. He then places the piece in an iron mold

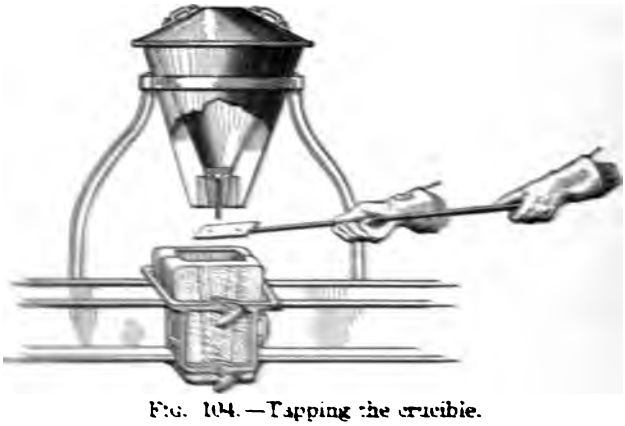

FIG. 104.—Tapping the crucible.

box, and tamps it around with wet sand, at the same time inserting wooden forms for pouring gate and riser: he next turns the flame of a gasoline torch into a special hole in the bottom of the sand box. The wax melts from around the piece and runs out of the hole. The flame is continued until the sand is dried, and then the operator stops the bottom hole in the mold with a sand plug. As already suggested the amount of thermit powder necessary for such a mold is thirty times the amount of wax, by weight. It should take less than twenty minutes to place a wax collar on an ordinary break and twenty minutes to dry out the mold. The cost of the wax is thirty-five cents per pound, so that for repeating occasional or oddly shaped breaks the wax mold is the cheapest and quickest. It is used for welds of em-

bossing- and stamping-press pieces, forging hammers, stern-posts and rudder-posts of sailing vessels, gun-carriages, motor cases, etc., etc.

Practice.—It should be borne in mind that the thermit joint itself is a steel casting of average analysis of:

Carbon	0.05 to 0.10
Manganese	.08 to .10
Silicon	.09 to .20
Sulphur	.03 to .04
Phosphorus	.04 to .05
Aluminum	.07 to .18

Its average tensile strength is about 30 tons per square inch cross-section. If the joint is good, the thermit will amalgamate so closely with the metal of the welded parts that a ground and polished section of the joint will not show any marks of junction, even though the metals be of different color and structure. Therefore, the operator has only to calculate whether he shall vary the chemical composition of his thermit to give his weld the desired strength or whether he should gain strength by casting a big shoulder on the joint.

There are a number of instances where the shoulder must be machined off, though the weld must be as strong as the rest of the piece, as in the case of rails, bearings, etc.

Most welds permit of the collar or the thermit steel reinforcement being left on after the weld is completed. It should be left on wherever possible as it adds to the strength of the repair and tends to prevent further breakage under the same strains that caused the first break.

In many cases, however, it is necessary to machine off this metal and where this is done the thermit weld will usually have about 80 per cent. of the strength of the original section. Usually fractures in crankshafts and similar sections are due to defects in material. If properly designed they should have a factor of safety of five. When welded and the thermit steel reinforcement removed they will still be amply strong as the defect will be eliminated and they will have a factor of safety of four which should be ample for all ordinary conditions.

Preheating is a most important step in the proper welding with thermit and it has been found that unless the sections are red hot before pouring the thermit steel, the weld is apt to contain blow holes (Fig. 105) as the steel chills before the gases have an

opportunity to escape. When the sections are red hot, however, and the proper quantity of thermit used, good dense homogenous metal will always result.

Setting the Pieces.—Where two pieces of steel are to be joined, it is best to allow from 3/4 inch to 2 inches between them (depending on the size of the sections) to allow for a free flow of thermit steel.

In the case of locomotive frames or fractures in heavy pieces of steel, it is often necessary to cut this metal out either with an oxy-acetylene flame or by drilling a line of holes along the break and then cutting out the metal between the holes.

It is always necessary when making a thermit weld to allow

FIG. 105.—Reproduction of photograph of a weld showing "blow" holes.

for the shrinkage of the metal in the weld. In locomotive frame work the parts are expanded by means of a jack or wedges from 1/8 inch to 3/16 inch and this expansion is held up until the metal in the weld has set, after which the jack or wedges are removed and the pieces will contract properly so that no strains are set up in them. In case of driving-wheel spokes it is often necessary to heat adjacent spokes so as to expand them equally with the spoke being welded. When the weld begins to cool the heat on the other spokes is removed and all the spokes cool down together.

Cleaning the Pieces.—It is important that the parts to be welded be thoroughly cleaned by means of the sand blast so as to show good bright metal for at least 4 inches on each side of the

fracture. This will ensure the elimination of scale, grease or anything else which might interfere with the perfect amalgamation of thermit steel with the sections to be welded together.

Preheating.—It is necessary to heat with the gasolene compressed-air torch all pieces to be welded for the reason that the molten thermit steel would be chilled if it came in contact with cold sections; the result would be an inferior weld containing blow holes. Gasolene is the only medium that should be used for heating as it gives perfect combustion without carbon deposit. Kerosene or crude oil on the other hand is apt to deposit carbon on the surface to be welded which might interfere with perfect amalgamation with the thermit steel. As to temperature, the sections should be at a good bright red heat before the thermit steel is poured. This is entirely possible with the preheaters which the company has perfected for the purpose, no matter how large the sections may be.

Safe-guarding the Mold.—Bear in mind that liquid thermit is excessively fluid—as much so as warm molasses—and as it is much heavier, it will search diligently for all openings in the mold. For this reason the mold must be tight at the entering of the iron pieces. The operator should have at hand a bucket of *luting clay*, made of equal mixtures of fire-clay and sand, made pasty with a little water.

If the molds are solid pieces, as in rail and locomotive-frame welding, he smears a thin layer over the surface of the molds where they come in contact with one another. This will make a fairly tight mold.

Also he must stuff luting clay around the mold where the iron pieces enter, otherwise the thermit may find its way along the iron and spurt out. The danger of an unexpected squirt of thermit need not be dwelt on.

When the mold is made of fire-clay tamped over a wax collar, there should be no leaks if the operator is careful. He must be sure that his mold is rigid and strong enough to hold the extra weight of the pour.

A possible overflow of thermit and slag must be provided for. Large pours of thermit are always made with this in mind. If the pour is made in the workshop, the floor should be of sand and the workman should remove his tools before tapping. After tapping the thermit he should remove himself as quickly as possible.

The company now furnishes molds that are hollowed out on top to form a basin to hold the slag so that nothing overflows.

Amount of Thermit.—Thermit gives half its weight in steel, and in estimating the quantity for a weld one-third more thermit steel than is required for the weld proper should be allowed for the riser and pouring gates. The first of the thermit pour that reaches the inside of the joint expends most of its heat in raising the temperature above redness. It passes up the riser leaving the interior so hot that the last of the pour settles easily around the half-molten joint and is fluid enough to make a homogeneous casting. It is best to calculate the thermit from the wax; allow 25 pounds of unmixed thermit to the pound of wax and then add 1 per cent. pure manganese, 1 per cent. nickel thermit and 15 per cent. of mild steel punchings. These punchings should not exceed 3/8 inch in diameter by 1/8 inch thick, and should be clean and free from grease. The company also supplies a special *railroad* thermit made of ready mixed thermit, manganese, nickel thermit and punchings, and when this is used, one allows 30 pounds of it to the pound of wax. However, P. Redington[1] and H. L. Des Anges[2] advise that *three* or even *four* times the amount of steel is needed to get the best results. This may be due to imperfect preheating.

The Reaction.—The reaction is rapid and violent. There is no explosion, but the crucible sends up a shower of sparks much like the kind of fireworks called a "flower-pot." So to prevent this and to conserve the heat, a loose metal top is slipped over the crucible as soon as the fuse is lit.

The workman should use smoked or colored glasses to protect his eyes.

The reaction takes not longer than thirty seconds. The crucible should not be tapped for at least ten seconds thereafter, because the reaction has left an intimate mixture of slag in steel in the crucible, and a little time is allowed for the slag to float to the surface.[3] I believe that outside of insufficient preheating, one of the common causes of failure of thermit welds is premature tapping.[4] No steel is strong if it is permeated with slag.

[1] *Foundry*, April, 1905.
[2] *Foundry*, August, 1905.
[3] *Ibid.*, R. Webb, July, 1905.
[4] *Foundry*, Jas. F. Weber, July, 1905.

After Pouring.—After pouring, you have an ordinary steel casting, with this exception—that the heat of the joint will be conducted by the body of the part much faster than is good for a steel casting. If you are welding a fractured locomotive frame, and you want to assure yourself that the joint will be as tough as the frame you had best give the joint several hours' annealing by such means as are at hand.

Annealing is not so necessary in a thermit joint as it is in the oxy-acetylene and other welds. Thermit steel shows a low-carbon content. Rapid cooling will not temper it highly. But no chilled steel is as tough as the annealed product. Tests in practice seem to show that after-heating gives an even-grained and tougher joint.[1]

The results of after-heating may be attained in a lesser degree by keeping the mold in place until the joint is cooled. Cooling may take several hours with the mold on if the pieces are large.

Nickel Addition.—Nickel thermit is an allied substance to thermit proper. It is a mixture of nickel oxid and aluminum, and the reaction sets free the nickel in the metallic state.

$$3NiO+2Al=3Ni+Al_2O_3.$$

If the operator wants a higher tensile strength without diminishing his elastic limit, he introduces nickel thermit. The nickel thermit is fired in a hand-ladle, using a small quantity, and pouring in the remainder of the package gradually as the reaction progresses. The entire contents of the hand-ladle are poured into the big ladle, which should be one-third full of molten iron. The big ladle is then poured full of iron and a can of titanium thermit is poled in to cause a thorough mixing of the iron and nickel.

One per cent. of nickel is sufficient to increase the strength of ordinary iron about one-third. Two per cent. of nickel thermit gives a little more than 1 per cent. metallic nickel.

Titanium Addition.—Titanium thermit is another "alumino-thermic" substance having the reaction

$$3TiO_2+4Al=2Al_2O_3+3Ti.$$

It is introduced into the ladle in foundry practice for the purpose of purifying the iron. About 1 per cent. is recommended. As its office is to reduce the sulphur and nitrogen, most of it re-

[1] *Journal U. S. Artillery*, Gustav Reiniger, July-August, 1907.

appears in the slag. Its effect is to greatly increase the strength, presumably by making the metal close-grained and homogeneous.

Butt-welding of Pipes.—One of the unique applications of thermit is in the butt-welding of pipes and bars. It is a very difficult and often impossible thing to make a strong joint of two gas or water pipes without cutting reverse threads on the two and using a sleeve union. Welding such joints by ordinary means is generally out of the question, because with the facilities ordinarily at hand, it is difficult to obtain the right welding heat, and almost impossible to keep the surfaces clean enough to join them. Furthermore, if all preliminary conditions were met, the pipe ends could not be joined without mashing in the pipe walls to some extent.

In using thermit for butt-welding, the slag of the thermit reac-

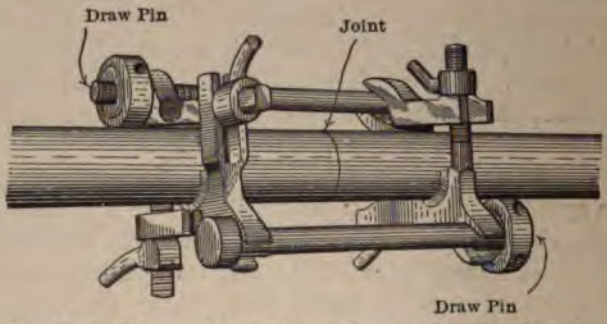

FIG. 106.—Clamps in position. Pipe welding by thermit.

tion is poured into the mold before the metal. It covers the iron surface in a thin layer that is at once chilled and adheres to the metal. This coating of slag serves as a distributor of the heat of the thermit metal to the iron, at the same time preventing direct contact of the thermit metal with the pipe. As soon as the operator believes the pipe ends are plastic, he pulls them tightly together, and the weld is effected.

As this is a very practical and necessary weld, it will be well to explain the operation and the appliances in detail.

Suppose two 1-inch abutting gas pipes are to be welded. The ends are first cut square and filed to smoothness, so that when the pipes touch their ends shall fit closely all around. Clamps are then fitted on the pieces, about 5 inches from the ends, and screwed tightly on the pipes. These clamps have sockets for

two connecting draw screws, which are fitted in place and tightened with pins (see Fig. 106) until the pipe ends touch. Brace the pipes so that they align as they should and place the lower mold jaw under the joined ends of the pipes, so that the line of joining is in the middle of the mold. This mold is a hinged affair, having two handles, and resembles a nut-cracker (see Fig. 107).

The thermit portion, about 2 pounds, is poured into a small cup crucible, which is lined with magnesia and operated with a pair of tongs. Allow the crucible to stand half a minute after firing, so that the slag and steel can separate. Then pour over the lip of the crucible so that the slag comes out first. Begin pouring at one end of the lip of the mold and travel to the other end. As the thermit slag is poured in on a cold surface of pipe, it forms a hard shell around the metal, and the liquid which follows distributes its heat evenly through this shell, which is a poor conductor. During the pouring, the operator's assistant

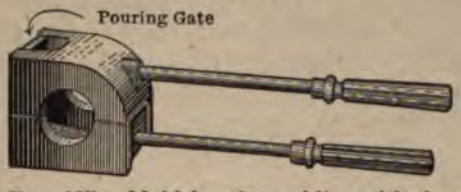

FIG. 107.—Mold for pipe-welding with thermit.

presses the handles of the mold together to keep the mold in close contact with the pipe. About one minute's time is allowed for the iron of the pipe to reach welding heat. The draw pins are put in the sockets of the clamps and screwed tight. If the pipe ends are plastic and ready to weld, the operator can feel it by screwing the draw pins. The nuts on both pins are given two full simultaneous turns by the operator and his assistant. This is enough to force the pipe ends together and complete the weld. If the operator desires, he can force enough metal into the upset, by giving the draw nuts another turn, to make the joint considerably stronger than the pipe itself.

The mold is taken off at once by tapping the upper jaw loose with a hammer. The slag collar which adheres to the pipe is knocked off carefully, and the red-hot joint is allowed to cool.

The draw bars and clamps which held the pipes together are removed as soon as the weld is cooled. The joint will have a

slight upset due to the extra metal forced into it. This may be machined off if necessary.

Tests on such a weld will give a fracture or a crease in the pipe outside of the line where the mold fitted.

The foregoing weld was made on a horizontal piece of piping. For an inclined or vertical piece, the apparatus and process are the same, except that the mold will have its mouth placed in the side so that the thermit can be poured in when the mold is in place (see Fig. 108).

FIG. 108.—Clamps and mold in place for welding vertical pipe.

For pipes or rods of different thickness or diameter, the size of the mold will vary, also the amount of thermit to use and the time it takes to raise the joint to welding heat. The manufacturers supply both molds and clamps for pipes and rods of standard sizes, and specify the amount of thermit to use in each case.

In this application of thermit, it should be noted that the thermit steel does *not* come in contact with the pieces to be welded, nor does its substance form a part of the weld. Accordingly, thermit butt-welding is applicable to pipes and rods of wrought iron and mild steel, and *not* to cast iron and high-carbon steel.

This process can be used for welding gas and water pipes while in the ground; steam and ammonia and compressed-air pipes; pipe coils, before or after bending; steel rods in reinforced concrete.

The entire cost of making one weld for a pipe of 1-inch bore is approximately $22. This includes the total cost of the apparatus necessary, and the time charge of one hour at thirty cents for the operator and twenty cents for the helper. This prohibitive cost is rapidly reduced for welds in number, just as the cost of a printed page rapidly decreases as the number printed increases. One hundred welds like the above would cost, approximately, one dollar each, supposing that two welds could be made per hour. The first cost of tongs and clamps is final, while the crucible must be replaced after about ten firings and the mold after fifty welds. The cost of the thermit and the ignition powder and also the labor is a constant.

One of the rivals to this welded joint is the plumber's sleeve joint. In comparing the two methods of joining, the contractor must consider several things; will it be cheaper to cut a thread on each pipe end and sleeve the joint? Also, will it be possible for the workman to get at his joint to cut the thread? Is a leak at the joint going to be a vital matter? A weld cannot leak, while any other joint is apt to under pressure, especially where the pipes are cold, as in ammonia plants. Will a sleeve joint be strong enough in cases where the pipes are subject to strain? And, finally, how do the total costs compare? This last will depend largely on the number of joints to be made.

Another rival is the oxy-acetylene-blowpipe weld. It is probable that with this method one workman can make from one to four welds an hour, depending on the amount of labor he must put on cutting and fitting the pipe ends preparatory to welding. This, together with the cheapness of the gas used, makes the operating cost much less than the thermit butt-weld. However, the cost of the apparatus, two gas storage tanks, the blowpipe, and the check valves, is much greater. Also, to travel from pipe to pipe, often necessary, the operator would need an assistant to carry the heavy tanks, etc.

Butt-welding of pipes can be done by the Thomson electric process. But this process is at a disadvantage here because the welding must be carried on in a heavy machine. Whereas, when pipes are to be butt-welded, the chances are that they are in some out-of-the-way corner of a room or cellar and cannot be taken out.

Mending Defective Castings.—Besides its use in welding, thermit is being exploited for the repair of defective castings, which is not strictly a welding operation. Also for raising the temperature of the ladle before pouring for castings; for poling "burnt iron"; for the introduction of nickel, titanium, etc., into molten iron; for the formation of alloys; for the reduction of the less common metals from the refractory ores and earths. Though these last have nothing in common with welding, they will be treated of briefly, so that the treatise on thermit may be complete.

In the foundry, in the casting of large and expensive pieces, the loss by defective castings is sometimes equal to the price asked for the casting, due to cracks, bad flows, breaks, and inopportune blow holes. If the foundryman can save such pieces from the melting pot, he will greatly increase his profits.

For mending small surface defects, where the idea is to replace the surface without regard to the strength of the patch made, the following method is advised. First, chip out the defect to be sure that it is superficial. Heat the casting around the hole to a red heat. Then bank a basin of sand around the hole. Place a piece of asbestos in the bottom of the basin, large enough to cover the hole. Pour thermit powder into the basin, using 18 ounces of thermit for every cubic inch estimated space of hole in the metal. If the casting is a large one, use a greater percentage of thermit, as more heat will be needed. Fire the thermit, and it will quickly melt the asbestos bottom, and the molten steel will be deposited in the hole in the metal. When cool, the protruding metal is machined off.

FIG. 109.—Thermit can plunged into ladle.

This reaction is too rapid for the complete separation of the slag, some of which may be lodged on the junction of the thermit metal and the casting. Also, it is likely that the local heating will cause weakening stresses in the patch when it cools; while it may also be full of blow holes if it cools rapidly, because of conduction. It is claimed[1] that the shrinkage is so great that such a repair is unsafe and useless.

Thermit may be used for repairing fractures in castings before they leave the foundry. If the casting have a piece broken cleanly off, this may be joined at a less cost than the cost of recasting. Also cracks may be drilled out and thermit used.

Thermit in Foundry Practice.—Thermit may be introduced into the ladle before pouring for a casting. If the piece to be cast is long and thin, or if it has intricate parts which require a very hot metal to produce, the temperature of the iron in the ladle can be raised by plunging a can of thermit into it and holding it at the bottom until both thermit and can have burned up and the slag has come to the surface. The excess heat of the thermit will raise the temperature of the ladle (Fig. 110).

[1] "Mending a Casting with Thermit," Pat Pedington, *Foundry*, April, 1905.

How much thermit to use for a given amount of iron cannot be stated definitely—probably 5 per cent. It depends on the initial temperature of the ladle, the demand of the casting, and the *cost*. The cost prohibits its use except for special work, such as the casting of stern-posts for ships, and the production of small castings which can be made at any time without the capital investment for a special converter plant.

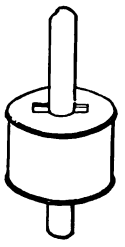

FIG. 110.—Detail of thermit plunger can.

The company also recommends placing a can of thermit in the riser of such a casting as a ship's stern-post. If the post is to be a long one, "the metal cools very rapidly during its passage through the mold, and becomes so sluggish that the pressure of the runner is not sufficient to force the metal up the rising heads more than one-half of their length." The thermit can will reinforce the heat of the rising metal.

FIG. 111.

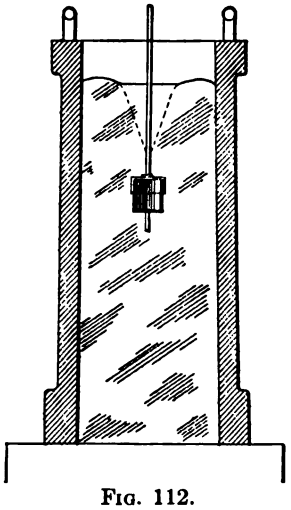

FIG. 112.

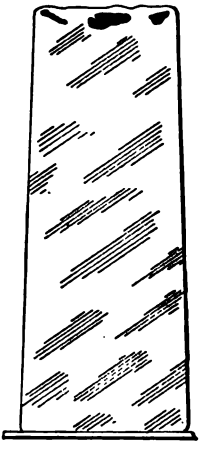

FIG. 113.

FIG. 111.—Steel ingot showing defective head piping without anti-piping thermit.

FIG. 112.—Showing ingot with box of anti-piping thermit in position.

FIG. 113.—Ten-ton steel ingot having been treated with anti-piping thermit.

To Prevent Piping.—A special anti-piping thermit is now made which is used in the following manner. Sometime after an ingot is formed, the steel has begun to solidify on the sides and

top and the contracting metal draws down from the top leaving a pipe, shown in Fig. 111. At a certain stage in the cooling, after the top has solidified, a can of anti-piping thermit on the end of a rod is thrust through the top crust near to the bottom. It ignites and burns violently, thoroughly mixes up the molten steel, and sends the slag to the top. As a result the nearly solidified steel settles in the mold 3 to 6 inches. Then enough hot steel is poured in to fill the ingot up to the crust.

The resulting ingots are claimed to be more nearly uniform in texture and composition. They are nearly free from pipes and require very little scaling. The scrap croppings cut from these ingots are about [illegible] per cent, from defects. In an instance a [illegible] ingot [illegible] shown before. The [illegible] was $[illegible]. The net gain was $[illegible]

[illegible]

Poling. [illegible] workman often freshens [illegible] with a green stick of wood. [illegible] This [illegible] much. By [illegible] workman has added [illegible]

[illegible] steam which [illegible] motion compare [illegible] the bulk [illegible] lowers the temperature [illegible] thermit can in the [illegible] composition [illegible] effect in the [illegible] a minimum. [illegible] temperature [illegible] kept [illegible] compare [illegible] While at the [illegible] would [illegible] would not [illegible] would say [illegible] that over [illegible] the use of

manganese with the thermit, though no doubt the thermit can be omitted if we do not wish to raise the temperature. Pure manganese, made "thermochemically," can be used. Manganese, in the form of ferro-manganese and spiegel, have long been known to furnace men as a cure for "burnt iron" and a toughener of their product.

W. M. Carr[1] is authority for the statement that a large ladle can be used for a small converter if thermit be added to the first pour in the ladle immediately preceding the second pour. The ladle held 5 tons, the converter 2 tons, the pours were forty-five minutes apart. The thermit was poled into the first pour, as usual, in a can on a rod. It freshened the iron and raised its temperature to about that of the second pour.

Adaptability.—In summing up the thermit process as a whole it will appear that it is especially suited for welding and repairing large pieces. In pieces ranging below 4 square inches cross-section, it has to meet competition with the oxy-acetylene, oxy-gas, oxy-hydrogen, electric, and smithing processes. Its application to butt-welding is very often the cheapest, handiest, and most workmanlike.

In rail welding it has to compete with the electric process, which was the pioneer in this field.

In welding motor cases for steel cars it has to compete with the oxy-actylene process.

In welding fractured locomotive frames it is used with success, and is evidently as cheap as can be had—certainly, much cheaper than the old blacksmithing, for the weld may be affected often without dismantling. It is used in their repair shops by many of the railroads in this country and abroad for repairing engine frames and also driving rods and spokes, and occasionally the repair machinery. The Central Railroad of New Jersey first introduced thermit in their shops.

It is used for occasional repairs of fractured gun-carriages and parts.

Also for crank shafts, embossing dies, shears, and anvils, in cases where it is cheaper to repair than to replace.

For broken rudder and propeller shafts, skegs, and stern-posts of vessels it is invaluable. This is the most notable feature of the process. Before the advent of thermit, a break in one of

[1] "Development of the Thermit Process in Foundry Practice," *Foundry*, July, 1906.

the parts named meant the dry-docking of the vessel for weeks, the displacing of the part broken and its repairing at great expense and trouble, or sometimes its displacement. Besides the actual expense entailed, much was lost by having the boat out of commission.

Since the use of thermit for such repairs, dry-docking is still necessary, but the whole operation can be gone through with in much less than a week; the vessel is not dismembered and the weld may be made the strongest part of the piece. Broken anchors can be mended in a few hours. As already described, there are many instances of such quick, cheap, and strong welds.

laide, Australia; the welding of the Lexington Avenue line in New York City. The latter was especially difficult because of the heavy traffic. It was impossible to do the job by daylight without tying up the traffic. In the early morning hours, when the cars run on a ten-minute schedule, the company succeeded in carrying on their welding with only the occasional holding up of a car.

The cost of rail welding varies considerably on account of the range in size, and it depends also on the number to be welded at once. From $8 to $12 per joint for material and labor is about right for the insert method first described.

FIG. 115.—Rudder frame of U. S. Torpedo Boat Destroyer "Paulding," welded at the Brooklyn Navy Yard.

Among pipe-welding contracts, that carried out for the Manhattan Refrigerating Co.,[1] of New York City, is noteworthy. Their entire system of piping was welded by the thermit process. There were twenty-nine 1 1/4-inch joints, and twenty-seven 2-inch joints, both under a cold pressure of 180 pounds. The result is reported as successful. This is a decided improvement on the sleeve joint for ammonia systems, because the contraction of the pipes due to the extreme cold is certain to allow leakage in the sleeve joint.

[1] *Iron Age*, Nov. 16, 1905.

REPAIR OF THE "BETSY ANN"[1]

"One of the quickest repairs on record was accomplish
Mississippi River Steamship "Betsy Ann," belonging to Learn
Natchez, Miss. This is a stern-wheel boat, the shaft being a
one, 8 3/5 inches on the inscribed circle and over 21 fee
crack developed on one of the lugs and ran down a short
second face, the total length visible being about 4 inches.
was first called to this by rust showing through the paint

weld of S. S. "Betsy Anne" before remo
left in gate and riser.

carefully it was decided to run the stea
Within a short time it was noticed
inch since the first observation, a
that a repair of some sort should be mad
were made to weld a collar of Thermit st
and thus to restore it to its origin
chipping hammer was used for cut
the flaw, so that the superheate
part. After this had been acc

Goldschmidt Thermit Co.

the paint was cleaned off a distance of 5 inches on either side of the fracture and the weld effected by the wax pattern method, as previously described; 416 pounds of Thermit, 35 pounds of mild steel punchings, and 8 pounds of metallic manganese being required. After allowing five hours for the metal to set, the mold box was removed and the weld found to be so satisfactory that the steamer immediately proceeded on her trip without waiting for the gate and riser to be cut off; in fact, the repair was accomplished without causing the steamer to miss a single trip."

REPAIR ON STEAMSHIP "CORUNNA"

"This was a vessel of 1296 tons register, 240 feet long, 35 feet beam and 12 feet depth. In getting away from her pier in the Lachine Canal,

FIG. 117.—Finished weld on rudder post of steamship "Corunna."

Montreal, the stern of the vessel was caught by the current and swung against the stone wall of the canal, the shoe or skeg being broken off close to the keel, while the rudder-post was broken at a point about 10 inches from the top of the rudder. Owing to the serious nature of the injuries it would ordinarily have been necessary to tow the vessel to Cleveland (there being no adequate dry-dock in Montreal to make these repairs in the usual way).

"It was soon decided that, without doubt, several thousand dollars could be saved by repairing the frame and rudder-post with Thermit.

"On inspection it was found that the rudder-post was broken off inside of the tube, while the stern frame had been bent 12 inches out of line, the shoe being completely broken about 13 inches from the central line of the post. On account of the break in the rudder-post being by an old scarf weld, fully 11 inches in length, it was not deemed advisable to attempt to weld this again, so about 14 inches of the rudder-post adhering to the rudder was cut off and a new piece of shafting, 8 feet

FIG. 118.—Thermit weld on stem post of steamship "Sachem."

long, welded on in place of the old post, as shown in the illustration. In order to facilitate the operation, the rudder was removed from the ship and the post welded on shore, this being done to prevent interference with the operation of welding the stern frame.

"It being necessary to have a supply of compressed air in order to operate the gasolene torch and pneumatic tools, an old Westinghouse steam-driven air-brake compressor was obtained and mounted on board ship, the steam being piped from a donkey boiler. A receiving tank was placed on the edge of the boiler and piped to the compressor.

With the apparatus in place, preparations were made to effect the welds in the usual way, the rudder-post weld being reinforced by a collar 3 inches long and 1 inch thick, while the stern-post was reinforced with a collar 8 inches long, 1 inch thick at the top and sides, and 3/4 inch thick at the bottom; the latter being done in order that the draught of the vessel might not be made any greater than could be helped. One hundred and fifty pounds of thermit, 25 pounds of steel punchings, and 3 pounds of metallic manganese were used in welding the rudder-post, while 350 pounds of thermit, 70 pounds of steel rivets (1 by 3/8 inch in size) and 7 pounds of metallic manganese were required for welding the stern frame.

"While the total time required for the operation amounted to five working days, there is little doubt that had the work been done in a properly equipped dry-dock, it could have been accomplished in three days or less."

WELD OF ELECTRIC MOTOR SHAFT

"It has usually been deemed necessary to leave a reinforcement or collar of thermit steel around the various welds made by the thermit process. An instance has occurred recently, however, where this reinforcement was machined off and the weld subjected to very severe strains, but without causing any weakness to show up.

"The case in question is that of an armature shaft 3 inches in diameter, 14½ inches long, and required to transmit 50 H.P. to the main hoist of a 50-ton Shaw electric crane.

"The weld was made in the shops of the Central Railroad of New Jersey, Elizabethport, N. J., and the armature has now been in service since October 8 and is giving perfect satisfaction in spite of the fact that all the surplus metal about the weld was machined off and the shaft turned down to its original diameter.

"The weld was made 9 inches from the hub, and is shown in the accompanying illustrations" (Fig. 119).

Chemistry and Thermics.—The chemical formula for the present thermit reaction is

$$8Al+3Fe_3O_4=9Fe+4Al_2O_3.$$

Expressed in weights, it is

217 parts aluminum+732 parts magnetite=540 parts metallic iron+409 parts slag,

or, approximately, 3 parts of aluminum and 10 parts magnetite will produce, on combustion, 7 parts metallic iron.

Commercial thermit is a mixture of finely granular aluminum with less finely granular magnetic iron scale. The aluminum is about the fineness of granulated sugar; the scale is like coarse

FIG. 119.—Weld made at shops of the central railroad of New Jersey on a motor armature shaft.

sand. The ratio by weights is three of iron scale to one of aluminum. Dr. Goldschmidt began his experiments with similar mixtures about 1895. Thermit was not heard of before 1902. He speaks with feeling of the mechanical and chemical diffi-

culties that hindered the perfection of his ideas. So there is good reason to suppose that the thermit mixture is about the best that can be made, both in its physical form and in its reaction. The difficulties that confronted Dr. Goldschmidt were:

1. The violence of the reaction.
2. How to get a good homogeneous steel out of the reaction.

One of the troubles with thermit reactions is their violence. The burning of several metals, as calcium, is so brisk that the contents of the crucible boil over and metal and slag alike are lost. Probably for this reason the magnetic oxid was substituted for the hematite oxid. Early literature gave the reaction as

$$2Al+Fe_2O_3=Al_2O_3+2Fe,$$

but Dr. Goldschmidt[1] gives the present reaction as between aluminum and magnetite, and a casual examination of thermit by means of a magnet shows that magnetite is now used. It is likely that the magnetic oxid gives a slower burning than does the sesquioxid. The magnetic oxid is made of granulated rolling-mill scale.

The aluminum is powdered by a secret process. At present there are two known ways of pulverizing metallic aluminum. The first is to raise the metal to an approximate 600 deg. Cent., at which heat the metal becomes brittle and granular, and can be ground between rolls. The second way is to blow air through red-hot aluminum so as to partly oxidize the metal. It is then cooled to about 600 deg. Cent. and ground, the oxid of aluminum helping to separate the metal into fine granules.

As will be guessed, a small amount of thermit will burn more slowly than a large amount. The heat of a large burning, such as for repairing a propeller shaft or large engine fly-wheel, will be so intense that the crucible will boil and throw out part of its contents. To prevent this, from 5 to 15 per cent., by weight of thermit, of cold steel billets and turnings are added to the thermit before burning. This iron takes up the excess heat. Of course this added steel must be of correct chemical composition.

While it is important to keep down the boiling reaction, it is even more necessary to get a resultant steel that will be strong, elastic, and dense. The quality of the thermit steel will depend on its chemical composition. Good steel is low in sulphur, phosphorus, and silicon, and not too high in carbon. The follow-

[1] *Electrochemical and Metallurgical Industry*, Sept., 1908.

ing "Average Composition of Thermit Steel" is given by the Company:

Carbon	0.05 to 0.10
Manganese	0.08 to 0.10
Silicon	0.09 to 0.20
Sulphur	0.03 to 0.04
Phosphorus	0.04 to 0.05
Aluminum	0.07 to 0.18

Of course, to produce a steel of the above composition, the aluminum and iron scale that make up the thermit must be very pure. It would be a problem to obtain sesquioxid of iron of sufficient purity and at the same time as cheap as rolling-mill scale. Sesquioxid or hematite ore always contains one or the other of the impurities in considerable extent and is of variable composition; while, in using scale from Bessemer or open-hearth steel the impurities would be already known and would be much lower.

In regard to the proportioning of the mixture, the formula calls for 3 parts of aluminum to 10 of iron oxid; the thermit mixture is 1 of aluminum to 3 of the oxid.

In nickel thermit the reaction is $2Al+3NiO=Al_2O_3+3Ni$. By weight, it is 54 parts aluminum and 224 parts nickel oxid give 176 parts metallic nickel. Or, approximately, 1 part aluminum and 4 parts nickel oxid give 3 parts metallic nickel. Nickel thermit, however, contains 5 parts of nickel oxid by weight to 5 of aluminum.

Besides the aluminum-iron oxid reaction, a number of others have been and are being tried. It is possible that the future thermit may dispense with aluminum and substitute another metal for reducer. "Weldite," an English product, used silicon and aluminum with Fe_2O_3. Dr. Goldschmidt himself has tried other combinations: for instance, aluminum and calcium, which, according to Dr. Richards,[1] give a greater heat due to the formation of calcium-aluminum slag. He gives the probable formula

$$5Fe_2O_3+3CaAl_2=3(FeO.CaO.Al_2O_3)+7Fe;$$

and claims that 70 per cent. of the iron would be reduced from its oxide; and that one part calcium-aluminum alloy will produce one and four-tenths of liquid iron (metallic).

Calcium[1] alone can be used to replace aluminum, but the

[1] *Engineering and Mining Journal*, June 15, 1907.

reaction is so violent that sometimes the contents fly out of the crucible. The addition of 30 to 40 per cent. fluor-spar (CaF) or 10 to 20 per cent. quicklime (CaO) gives a saner reaction.

Heat of Reaction.—Richards[1] has calculated the heat of the thermit reaction as 2694 deg. Cent. The temperature commonly given by the manufacturers is 3000 deg. Cent. M. Féry, using his new radiation pyrometer, found the temperature of the stream of steel as it flowed from the crucible to be 2300 deg. Cent.—probably about right when one makes allowance for the chilling effect of the crucible. Taking the melting point of steel as roughly 1350 deg. Cent., the thermit steel is nearly twice as hot.

Testing.—The strength of an ordinary weld in wrought iron varies from 10 to almost 100 per cent. of the strength of an equivalent cross-section of the metal. In general, however, a weld made under proper conditions runs between 50 and 70 per cent. for high-carbon iron and between 60 and 80 per cent. for low-carbon iron. The strength of a thermit-weld is subject to quite as great variance, for the reason that thermit steel is a definite compound and may be of quite different composition from the parts welded by it. Also it is well to bear in mind that the initial strength of thermit steel itself is subject to variations due to the amount of included slag, air holes, and to the rapidity of cooling; also, the chemical composition can be varied by the addition of alloy formers, such as nickel, chromium, and manganese; and the addition of titanium and manganese in small quantities, which are purifiers.

A number of tests of different character have been made by the company and by railroad and repair shops, some of the results of which are given as follows:

Test No. 1.[2]

"At the St. Louis and San Francisco Railroad shops, Springfield, Mo., recently the following test of a thermit-weld was made:

"A section of a cast-steel frame, 4 by 5 1/2 inches, was welded by the thermit process. In making the weld 75 pounds of thermit, 12 pounds of punchings, and 1 1/2 pounds of manganese were used. For molds, fire-brick was used, cut to shape.

"After the weld was cold, the collar on the bottom and one side was planed off 1/4 of an inch below the original surface of the casting,

[1] *Electrochemical and Metallurgical Industry*, J. W. Richards, June, 1905.

[2] *Reactions*, Vol. I, 1908, published by Goldschmidt Thermit Co.

in order to show the place where the two metals had joined. The riser also was cut off, leaving the collar, however. The weld was absolutely solid, not a single blow hole appearing anywhere—not even in the riser.

"The welded section (now 3 3/4×5 1/4 inches), with collar 1 inch thick on top and on one side, was then placed in wheel press on supports 14 3/4 inches apart and a piece of hardened steel, 1 inch square, placed as shown in Fig. 120.

"A pressure of 170 tons was applied before breaking. The fracture started at the bottom outside welded section, extending into the center of the weld at the top. The fracture showed that perfect amalgamation of the metals had taken place.

"In comparing the strength of this weld with original stock, assuming a maximum stress in the outer fiber for cast steel of 60,000 pounds to

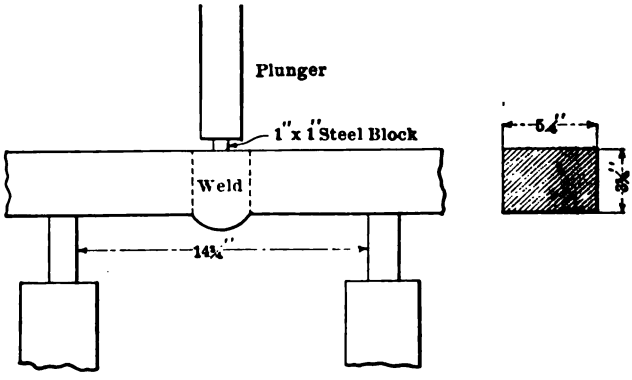

FIG. 120.—Arrangement of test piece for test No. 1.

the square inch, a section 3 3/4×5 1/4 inches tested in the same way would break at 100 tons."

In this test No. 1 it is presumed that the 12 pounds of punchings were mild steel. The manganese was used to freshen the iron, and most of it probably slagged as manganese oxid and came to the surface.

Test No. 2.[1]

"Two test bars taken from the upper part of a previously, but unsuccessfully, poured casting gave, on an average, 66,000 pounds per square inch tensile strength and 9.5 per cent. elongation on a measured length of 2 inches. This casting showed in all the sections a clean,

[1] *Iron Age*, April 26, 1906.

non-porous, dense grain. It appears possible, therefore, to produce steel castings of thermit and, in a case of necessity, the higher price would not be of importance . . ."[1]

Test No. 3.

The thermit process has been used by the Fore River Shipbuilding Co.,[1] of Quincy, Mass., who have made a number of tests of the physical properties of thermit metal. Bars of rolled steel, of section 2×4 1/2 inches were drilled, broken, and welded with thermit. Standard test bars were cut from the center of the welded bar, and were submitted to the ordinary tests. As the test pieces were of uniform size, both in the stock and the welded section, the result is worth recording:

TABLE 27

	Elastic limit	Tensile strength
Weld	32,000	59,000
Stock	38,000	60,500
Weld	33,700	61,800
Stock	36,850	63,400

It is to be noticed that the elastic limit is 12.7 per cent. less in the weld than in the stock, and the tensile strength 2.5 per cent. less—a fair showing.

TEST NO. 4.—BY THE ILLINOIS STEEL CO., CHICAGO[2]

C	0.05	Tensile strength..... 59,320 lbs.
Mn	0.10	Elongation..... 25.33 per cent.
Si	0.204	Contraction of area 59.9 percent.
S	0.04	
P	0.05	
Al	0.18	

TEST NO. 5.—BY THE PENNSYLVANIA RAILROAD, ALTOONA, PA.[3]

C	0.102	Tensile strength.....91,600 lbs.
Mn	2.330	Elongation in 8"..21.5 per cent.
Si	1.227	Silky fracture.
S	0.034	
P	0.07	

[1] *Journal United States Artillery*, Gustav Reiniger, July–August, 1907.
[2] *Transactions of the Society for Testing Materials*, E. Stutz, 1905.
[3] *Transactions of the Society for Testing Materials*, E. Stutz, 1905.

Test No. 6.—It has been suggested that the thermit-weld may be strong in itself, but that it weakens the adjacent iron. To find if this is so, a section of welded rail was subjected to equal blows by a steam hammer, both on the unaffected rail and on the metal nearest the weld. The die used was a blunt tool, 1 4 inch in diameter. Measurement with a micrometer showed a depression of 0.1432 inch in the rail nearest the weld and 0.1596 inch 3 feet from the weld.

Tests, under varying conditions without number, might be multiplied. But for the practical man, those already given show that the ultimate strength of the thermit steel in practice can be estimated as over 30 tons to the inch section. By practice, I mean the thermit steel produced for repair work, according to directions; thermit, about 5[1] per cent. mild steel punching, and about 2[2] per cent. manganese for purifier.

Annealing for 3 hours brings the elongation well over 10 per cent.

Addition of about 3[2] per cent. nickel raises the ultimate strength about 5 tons without decreasing the elastic limit. Further addition of about 2[2] per cent. of chromium with the nickel brought the elastic limit to about 47 tons—as high as can be wished. Addition of 1 per cent. titanium raises the tensile strength. Tests have also been made of thermit that has been toned up with molybdenum, ferro-silicon, etc.

[1] Calculated from weight of thermit powder.

[2] Calculated from weight of test bar.

PART V

MISCELLANEOUS WELDING AND SOLDERING PROCESSES

The Laffitte Welding Plate

The Laffitte process was invented in 1879 by a Frenchman, J. Laffitte, but it was not heard of in this country until 1905.[1] It formerly found its largest market in Germany and France. It is now used in many of the leading railroad repair shops, steel works, shipbuilding works and machine shops and manufacturing plants in this country.

It may be described as the handy application of a patent fluxing sheet between parts to be welded, and can only be used for joining iron and steel. The flux is sold as a plate 4 by 8 inches and two thicknesses, about 1/16 inch. This plate is composed of a special preparation molded over a sheet of wire gauze. The preparation gives the reaction for borax, besides which the company claims other chemicals which burn from a positive reaction as soon as the plate fuses, and this makes welding possible at a lower heat than the smith-welding temperatures, and also makes it possible to weld high-carbon steel.

Thus steel is welded at a cherry red.

The wire gauze is about 15 meshes to the inch length. Its iron is low carbon, about 0.08 per cent. by color determination.[2]

The pieces to be welded are brought to a cherry red and forced together with a Laffitte plate between the contacts. As with all smith-welding, one of the contact surfaces should be decidedly convex, so that the point of it is first brought to bear on about the middle of the other contact surface. As the two surfaces are forced together, with the plate between, the flux melts and flows out, fluxing both surfaces as it flows. The iron gauze, which is inside the plate, is also partly melted and welds itself in

[1] *Iron Age*, May 11, 1905.

[2] Specially analyzed by James De Long, Lafayette College, Easton, Penna.

place on both surfaces. It is likely that the strength of the Laffitte weld is as much due to the binding action of this low-carbon iron wire as it is to the complete fusing of the compound. If properly done, the weld should be flawless. It is not necessary

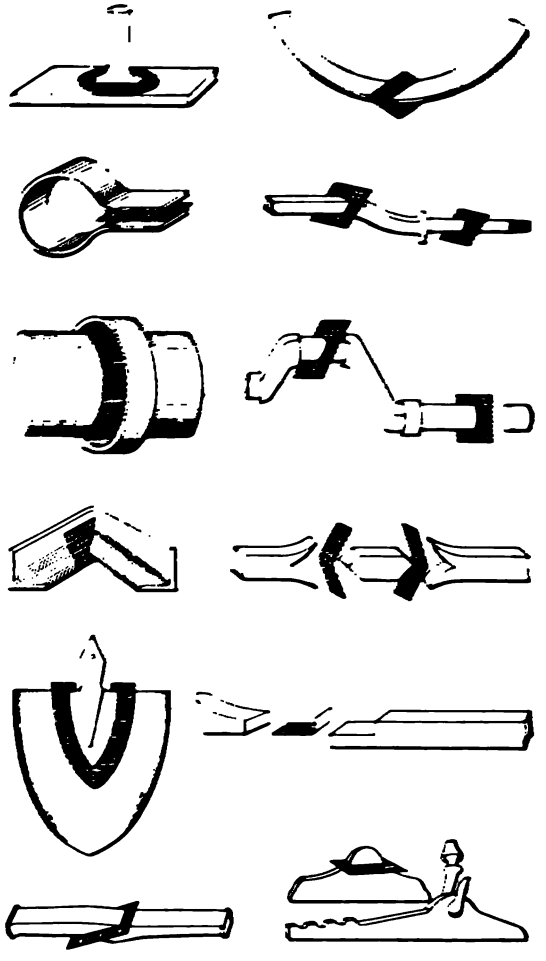

FIG. 121.—The Laffite welding plate showing its use and adaptability.

to use more of the plate than will cover both surfaces. The plate can be cut with ordinary shears.

From tests made it is claimed that the Laffitte weld is as strong as the metal, in case soft steel is welded; but that in high-carbon steel there is a slight lowering of the elongation and tensile

strength (due no doubt to the reheating of a specially treated product).

In all but one of these tests the tensile strength is greater for the Laffitte weld than for the body of the stock, which may indicate that an upset of metal was crowded into the weld by the pressure of welding; while with cast steel the quality of the metal might be improved by the pressure.

TABLE 28.—HARD STEEL TEST
Mn, 1.35; C, 0.45; S, 0.045; P, 0.083; Si, 0.08

	Before welding	Laffitte weld	Common weld
Tensile strength, kg...	70	63.6 68.0	55.9
Elongation, per cent...	15.2	10.0 11.6	2.5

The Laffitte plate has had its largest market in France and Germany. It is now used extensively in this country and comes into competition with the other welding processes. While it is well adapted to stock welding, such as the joining of axle parts and in chain welding, it is valuable for repair shop work. Thus it is used by railroads in their repair shops, by ship builders, boiler makers, steel plants, machine shops and manufacturing firms whose products or repair work calls for welds. The plate is adapted to job work such as blacksmiths handle (Fig. 121), and it finds its largest market with blacksmiths.

TABLE 29.—TEST BY THE FRENCH GOVERNMENT[1]—(Toulon Arsenal)

	Tensile strength, lbs.			Elongation, per cent.		
	Before	Special compound	Laffitte	Before	Special compound	Laffitte
Iron on iron.....	48,700	44,729	48,938	16.33	9.66	14.33
Iron on soft steel.....	48,700	43,964	45,631	16.33	4.—	4.—
Steel on soft steel....	75,935	72,197	80,500	2.—	1.—	2.—
Iron on cast steel....	75,935	43,719	78,692	2.—	3.25	9.05
Cast steel on cast steel.	95,030	92,712	102,711	5.62	3.—	5.—

[1] *Iron Age*, August 24, 1905.

FERROFIX BRAZING PROCESS

An ingenious and very good modern method of brazing broken iron parts (especially cast iron) goes by the name of the Ferrofix Brazing Process. It was devised by Frederick Pich, a German. By this process two fractured pieces of iron are cemented together with a thin film of brass which is so applied that it alloys with the iron surfaces, as deep as 1/16 inch. This was proven by cutting open a brazed joint and planing it down to ascertain its structure. To get this alloy in the joint, which is the secret of its strength, the solder must not melt below 650 deg. Cent.; hence hard brass is used.

Apparatus for Ferrofix repairing consists of:

1. A kerosene pressure tank and two or more Donnelly torches, which is an improved non-carburizing kerosene burner.
2. Fire-bricks and asbestos paper for a small furnace.
3. Ferrofix fluxing powder.
4. Patent brazing liquid.

The torch for heating may be air-coal gas, air-oil, oxy-acetylene etc.

The flux is a mixture of equal parts of sodium carbonate and boric acid, with a little common salt to increase fluidity.

United States patent paper, No. 688030, states that borax, the chief flux for all soldering and brazing, is troublesome because it swells up and falls off of the piece as soon as heat is applied. This, because it is then parting with water of crystallization. The patent flux, on the other hand, acts as follows: the carbonate is a ready absorbent of grease, of which it frees the iron surface. With the application of heat, the carbonate also reacts on the boric acid, forming anhydrous borax and carbon dioxid. The borax is thus in close contact with the fresh metal surface, which it frees of rust and protects from the air.

The soldering compound is described in patent No. 647632 as follows:

"To form my improved soldering compound, I boil together finely pulverized borax and finely pulverized suboxid of copper, so that the same are intimately mixed and so that each particle of the suboxid of copper is surrounded, covered, and protected from the atmosphere by a thin film of the borax. Any desired proportions of the two may be used; but usually I take one-half of each, mixed with sufficient water to dissolve the same thoroughly by the boiling, and to cool down into a sort of paste.

"To use this soldering compound, the cast-iron surfaces to be soldered are cleaned by means of an acid in the usual way, fixed together, and the joints covered or surrounded with the compound. The joint is then heated, and therefore the borax melts and protects the cleaned surface of the iron against oxidization, removes any oxid thereon, and also protects the suboxid of copper against the action of the oxygen of the atmosphere. Consequently the suboxid of copper, likewise heated to a red heat, transfers its oxygen to the red-hot cast-iron surface, which oxygen combines with the graphite contained in the cast-iron surfaces to form carbon monoxid or dioxid, thus decarbonizing said surfaces, while the metallic copper becomes dissociated in a very finely divided condition. At the same time the hard solder is added, and as this solder, which is brought upon the surfaces to be soldered in the well-known manner, is likewise melted by the heat, it alloys itself with the incandescent particles of copper, and this new alloy immediately combines with the red-hot decarbonized soldering surfaces of the cast iron."

The company also issue instructions, which are in brief;

1. "Clean fractured surfaces thoroughly with wire brush. If rusty or oily, burn off with torch.

"2. Mix Ferrofix powder with the brazing liquid to the consistency of paint and apply on the fractured surfaces with brush.

"3. Set casting to be brazed on fire-brick, in perfect alignment, using fire-clay to hold it in place (if it will not stay of its own weight). Be sure that the broken parts fit close. Build a furnace of fire-brick around the fractured part, allowing sufficient metal to be exposed, however, to absorb the heat. Leave top of furnace open, covering only with a sheet of asbestos—3/16 inch thick is sufficient ordinarily. The front of furnace should be left open to admit the torch blast.

"4. Place the torches so that the flame will come directly on fracture; bring casting up to a light cherry-red, almost straw. See that both sides of the fracture keep at the same color.

"5. Apply flux with a steel spoon (made from 3/8-inch Bessemer steel rod flattened out at one end) holding it at the fracture with the spoon, so that from the heat of the casting (not the torch alone) it will melt and disappear through the crack. As soon as it comes through freely and you can see the liquid flux underneath, apply spelter with a very little flux; feed this until it flows through thoroughly. With the spoon the melted brass can be taken from underneath and fed over until the crack commences to fill, then cut off immediately your air and gas, and keep feeding a little more new brass until it will not melt further by heat of casting. Allow to cool down by its own cooling.

"6. Clean casting with file, chisel, or emery wheel.

"The question of expansion and contraction is governed by the construction of the casting and the character of the metal. Care should

be taken to see that heat is properly applied and distributed to overcome this feature. Experience on intricate castings is the best teacher."

This is another comparatively new process that is beginning to be known by the foundries, car shops, blast furnaces, and machine shops. The first patent dates 1900. Its success is based on its cheapness, handiness, and strength. The initial expenditure is very low, the burner costing most. The outfit would prove a great saving to any plant which has breaks in its iron machine parts. For a fractured piece could be mended in an hour, whereas it is ordinarily necessary to rivet the old piece together with side braces or to order a new piece under danger of delay and hold up.

As for strength, the company guarantees that the joint is stronger than cast iron; brazed pieces never break in the joint. Moreover, the pieces to be mended are set as closely as possible, as the spelter will penetrate the tightest fracture.

There are "several tests covering the penetration of brass on cast iron treated with Ferrofix and also untreated. This was done by the taking three test bars which had the upper surface smooth, one was left uncoated, one had one coat of Ferrofix applied, and the third had two coats of Ferrofix. They were then placed in the furnace and heated to the same temperature, and the surface coated with brass as in brazing. When cold the coated surface was planed 1/32 inch below the original surface. We found on the untreated piece no evidence of brass, while on the treated pieces brass was distinctly discernible in the pores of the iron. Another 1/32 inch was then taken from the two treated pieces, and we found on the bar that had a single coating of Ferrofix minute traces of brass, while on the double-coated piece the brass was very distinct. It must, therefore, be apparent that the joint we obtain is not simply a surface adhesion, but an actual anchoring of the filling material to the adjacent faces of the fracture."[1]

TABLE 30.—TESTS MADE BY RIEHLE BROS.

Specimens 6"×6"×24" long. Cast iron. Supports 20" apart. Load applied at center of specimen.

Marked	Breaking strength in lbs.	After brazed
1	155,280	131,000
2	178,700	180,860
3	194,440	187,750
4	168,700	178,310
5	163,220	162,450

[1] Special information.

TABLE 31.—TESTS MADE BY RIEHLE BROS.

Marked	Area in sq. inches	Ultimate strain per sq. in. in lbs.	Remarks
No. 1. Brazed...	0.450	19,220	Broke outside weld
No. 2. Brazed...	0.439	20,570	Broke outside weld
No. 3. Solid	0.439	22,730	Broke

Two other tests by the same company showed increases of 1 and 6 per cent. for mended bars.

Of three tests by Lewis Foundry and Machine Co., the first showed an increase in strength of 1, and the other two a decrease, of 14 and 29 per cent.

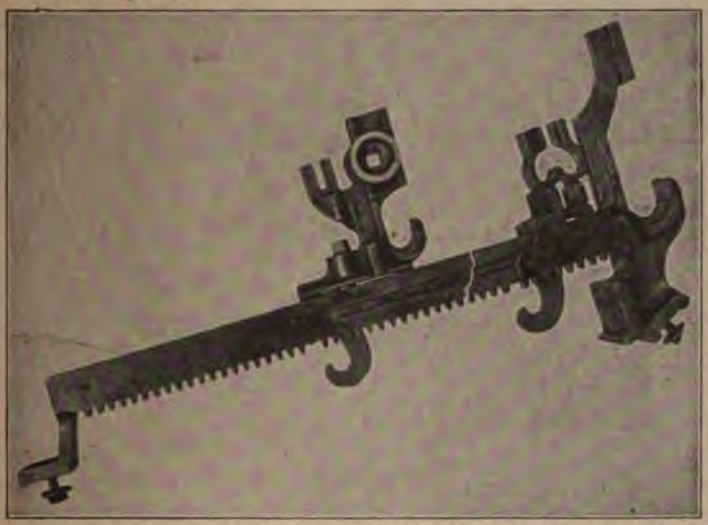

FIG. 122.—Broken arm that was made stronger than originally by the ferro-fix brazing process.

Two bars tested by Cramp's broke outside the joint.

The process is now used for all-sized repairs, small or very large.

"By accident a spoke was broken from a fly-wheel, 19 feet in diameter, 48 inches width of rim, weighing 21 tons. A new wheel would have cost $2700 and would have involved two or three months' delay. The Pich process was applied; the broken spoke was brazed into place, and $250 charged and paid for the job. The actual cost of doing this work was less than $50.[1]

Fig. 122 shows a break of an important appliance that can be mended by this process."

[1] *Proclamation of the Boston Society of Civil Engineers*, May 20, 1903.

BRAZING AND SOLDERING

Brazing and soldering are processes which are much like welding and which often shade over into welding. The brazing of brass is welding, except that the metal is not pounded together, but melted. The definitions for soldering and welding are given in the first chapter. Brazed and soldered joints resemble welded joints in as far as the solder and the metal of the piece or utensil amalgamate at the joint. But such joints are different from welded joints because the solder or spelter is of different composition from the metals it joins and serves the purpose of a go-between.

Brazing.—Iron, brass, copper, gold, and silver are the metals joined by brazing. The process is briefly: fluxing the metals at the joint, adding the brazing mixture called "spelter," heating until the spelter melts and works into the joint, finishing the brazed joint with the proper tools.

The flux used is either borax or boracic acid. The latter is used because it is cheaper; but for other than rough, commercial work borax is the better. Borax should be burnt or calcined before using to drive off the water of crystallization. If this is not done, the borax will swell up under the flame, will blister, jump, and much of it be lost. Whereas calcined borax simply melts on the metal, runs over the surface in a thin glass, and cleans the surface of oxid and grease.

Before applying the flux, it is well to clean the metal with a file and remove all grease with a rag or alkali water.

Besides borax there are a number of other chemicals which can be used, such as zinc chlorid, sal ammoniac, common salt, and the corrosive acids. None of these are as good as borax. The first two are properly soldering fluxes, the third melts too readily, and the acids are liable to remain in the brazed joint and to decompose it slowly.

A number of patent powders and liquid fluxes are now on the market. They are mixtures of the common fluxes in such form that they can be easily applied to the work.

Spelter for brazing is used to cover a range of hard and soft alloys, though spelter is supposed to be a half-and-half alloy of copper and zinc. Hobart[1] gives the following table of brazing alloys:

[1] "Brazing and Soldering," James F. Hobart, 1908.

TABLE 32

Brazing alloys	Tin	Copper	Zinc	Antimony
Hardest	0	3	1	0
Hard (spelter)	0	1	1	0
Soft	1	4	3	0
Softest	2	0	0	1

English books mention spelter as composed of 1 part of fine brass, 1 part zinc—in other words, 2 parts zinc, 1 part copper. The hardest spelter will give the strongest joint, provided the spelter amalgamates perfectly at the joint. It will also require the hottest flame to melt and will be more difficult to handle. Softer spelters give softer joints, work in easier, and are cheaper to handle. Brass and iron joints that do not have to stand strain nor long time test are brazed with softer spelters. Spelter is powdered or filed into shavings, and mixed with the flux; or it is cut into thin strips or small chunks.

The torch, for brazing or soldering, is used when the work is not on a large piece or when a forge is not handy. A gasoline or kerosene torch can be used for small work. A blacksmith's forge is better, because the piece can be heated slowly and evenly, and cooled the same way. The same restrictions apply for all fuel used as apply for welding (see page 4). The fuel should be free from sulphur and soot and the flame should be non-oxidizing. In the case of coal and coke, do not let the fuel touch the parts to be brazed.

As in welding, a gas flame is the best. The operator can build up a furnace of fire-brick, with one or more nozzles of gas pipe intruding. He can then regulate the size and direction of the flame, and heat and cool the work slowly and evenly.

Brazing work requires high temperatures: for iron it is done at a bright red, almost white, heat. This explains why the flame should be reducing and free from sulphur.

The gas flame varies from a blowpipe flame to that given by a two-way injector tube made of gas piping (see Fig. 123). The flame is a bunsen flame, with a blue cone.

To braze requires considerable variation in practice, according to the work at hand. Suppose the worker is about to braze

together two cast-iron pieces of a fractured bar. He first cleans the ends of the bar at the fracture by filing and scraping away all grease and paint and then cleans the fracture with a wire

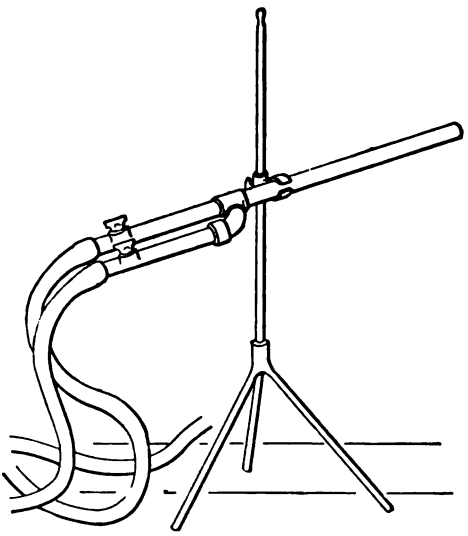

FIG. 123.—Air-gas torch for brazing.

brush. He then brushes the borax on the fresh surfaces or, in case a liquid preparation is used, he applies it with a brush.

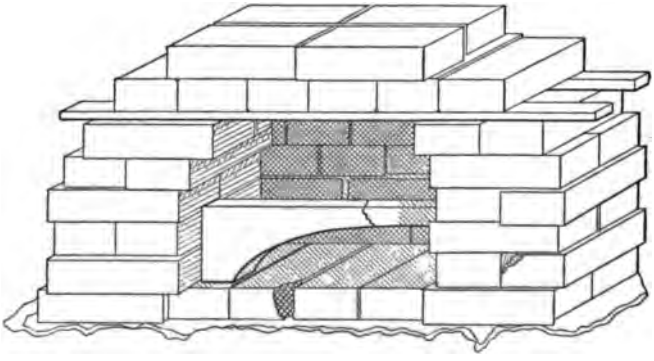

FIG. 124.—Makeshift brick furnace for brazing, showing broken casting in position.

He then places the pieces together as he intends to braze them, resting them on fire-brick, and builds up a little oven of brick around and over the pieces, leaving one wall of the oven open

for the flame (see Fig. 124). When brazing pieces or mending fractures, always press the surfaces as closely together as possible. No joint is too tight for the spelter to enter, while the tightest joint will be the strongest.

The burners are then brought up in front of the open oven and pointed at the work. These burners, for job work, are commonly made of two-way gas pipe with rubber hose for leading tubes. One tube carries the gas, the other the air blast. The air-blast tube is straight and draws in the gas by injection. The air blast is made by a motor-driven fan. For convenience these gas-pipe torches are swiveled on tripods. The air blast is started, the gas turned on, and the operator regulates the flame to an even blue cone by turning the cocks. The flame is directed at the work and kept there until the brazing is done. At a bright red heat, the operator sprinkles more brazing powder or borax on the edges of the fracture, and works it back and forth with an iron spatula. This cleans the iron surfaces at the fracture, so that the spelter will *wet* the iron and run down into the fracture; next he shovels some spelter over the fracture and works it back and forth as it melts down. If the fluxing has been right, the spelter will slip down into the crack and fill up the entire fissure, *wetting* the iron surfaces, and the excess will run out of the lower crack of the fracture.

The operator now turns off the flame and allows the work to cool. Cast iron will cool quickly; but if the piece to be mended is at all intricate or has long arms, care must be taken to allow for equal cooling and shrinkage.

Care must be taken in heating the work to be brazed that the heating is done evenly and that no part is overheated. In the case of brass, overheating spoils the metal as it burns out the zinc to some extent. A safe method in brazing brass is to paint the piece over with a graphite preparation, except where the brazing is to be done. The graphite is indifferent to flame and flux and will prevent the zinc from volatilizing. One of the objections to soft spelter is the amount of zinc it contains.

In the making of a number of utensils brazing plays an important part. For this reason it is important to do the work quickly. Much *repeat* or stock brazing is now done by immersion, the same as iron is tinned. The pieces to be brazed are painted with graphite wherever necessary, are heated, and then plunged into a bath of melted spelter, on the top of which floats the melted flux.

The flux cleans all of the metal unprotected by the paint, and then as the pieces are lowered further into the bath, the melted spelter readily wets the fluxed surfaces and brazes the pieces.

In brazing gold and silver, the alloy used is commonly a mixture of spelter with gold and silver; sometimes antimony, arsenic, etc., being added to reduce the melting point and to make the alloy fluid. This means that the process is really a soldering one. Brazing of gold and silver is a jeweler's art. It is done with small pieces and needs only a foot blast or a mouth blowpipe for the flame.

A brazed joint is commonly considered to be stronger than the adjacent metal. A brazed cast-iron piece will never fracture at the braze. Tests of well-brazed joints show them to be from 10 to 25 per cent. stronger than the iron. A brazed joint is inferior in a number of ways to a welded joint. In the first place, the electrical conductivity is not equal to the piece brazed. Then there is the danger that free acid, pieces of flux or rust have been left in the joint and will lessen the strength at once or by slow action. Then, under water, a brazed joint may become an electric couple, and the metal may slowly disintegrate. Lastly, it is found that joints will not stand concussion tests as well as welded joints. This is attributed to the presence of zinc, which is said to weaken the joint by its presence in the alloy.

Aside from these objections, a brazed joint is apt to be stronger than a weld, is generally cheaper, easier to make, takes less skill, apparatus, and time, and is often quite good enough for the purpose.

Soldering.—A solder is a metallic glue. There are almost an infinite number of solders, the most common being lead-tin solder for soldering the common commercial metals. The lead-tin proportion is varied to obtain solders with different melting points, strength, fluidity, and elasticity. Then other metals are added to the original lead-tin alloy, so that the properties of the solder are given a different range. The solder may be used for special metals and special purposes. Either the lead or tin or both may be dropped.

All solders have lower melting points than the metals they are intended to join; all solders must amalgamate with, or "wet," the metals they join. Most solders are weaker in tensile strength than the joined metals. For this reason soldered joints are not

often intended to be specially strong. When metals are soldered in preference to being brazed or welded, it is because time and money can be saved and a satisfactory joint gotten.

Ordinary solder is half-tin half-lead, by weight. Hard solder is two parts lead to one part tin. Hard solder is more brittle, stronger, and has a higher melting point. On account of the present high price of tin, it is also cheaper. To ordinary solder, antimony is added to still further harden and stiffen the solder. Arsenic is sometimes added to make the melted solder flow freely. Bismuth and cadmium are sometimes added to bring the melting point down. For example, Wood's metal contains two tin, two lead, two cadmium, and eight bismuth, and melts at 70 deg. Cent. Bismuth is apt to make a solder brittle; while cadmium, like tin, helps to make the solder elastic or soft. Copper in small proportion will stiffen and strengthen solder, but it will raise the melting point sharply. Iron is seldom used in solders.

The data on the proportions of these metals in the solders is very inexact, and the exact properties of a given alloy are seldom known. The whole subject comes under the study of *alloys*, in which there is still much confusion and little accurate information. New alloys are being put on the market every day, some of them of known constitution, some unknown; many of them have properties claimed which they do not possess, and the practical men must find out for themselves which of the solder alloys are fit for the purposes they are advertised for. The future will see more accurate information at the call of the metal worker, who will be able to choose his solder with an eye to getting certain properties in the alloy and at the lowest cost.

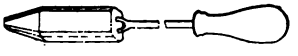

FIG. 125.—Ordinary soldering iron.

The *soldering bit* is a copper-headed tool used to melt and manipulate the solder. The head is of various shapes, according to the work at hand, and is fairly bulky so that it will hold heat for a period of time (see Fig. 125). It is also pointed so as to be handy for working into seams and corners. The bit should be coated around the point with tin or the solder that is to be applied. This is so that when hot it will be coated with a skin of melted metal which will draw the solder with it. To *tin* the bit it is first filed or sand-papered free of scale, is fluxed with zinc chlorid, and then heated. It is then tinned by holding a tin stick against it and melting off some of the tin, which will

adhere to the freshly fluxed surface. If the bit is at any time heated to redness while using, the tin will volatilize and the bit must be retinned.

An ingenious soldering bit, or iron, recently patented, is described in the *Brass World* for February, 1905. The body of the bit contains a small reservoir in which is placed the solder. The reservoir has an opening near the head of the bit, which is opened by pressing a lever on the handle of the bit. The reservoir is so designed that the solder will not spill out while the workman is using it.

Fluxes for ordinary plumbing soldering are sal ammoniac, borax, resin in alcohol, tallow, or zinc chlorid solution. There are a number of patent or secret fluxes on the market, and many metal workers make their own special preparations. The soldering flux is generally applied before heating and after the metals have been cleaned. Its office is to combine chemically with any oxid left after the mechanical cleaning and also to dissolve any grease. A well-fluxed surface is made of raw metal, ready to be wet by the solder.

Sal ammoniac may be powdered on or applied with a brush as a solution in water. Calcined borax is powdered on or its solution painted on. Zinc chlorid is made by dissolving zinc to saturation in dilute hydrochloric acid. It is considered the best flux for plumbing.

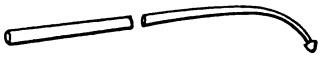

FIG. 126.—Ordinary mouth blowpipe.

Some solders are known as *self-fluxing*. They contain a metal which oxidizes when heated or which is a solvent for the oxid on the surface to be soldered. For example, Richards' aluminum solder is applied without flux. It contains phosphorus, which acts as a flux with oxid of aluminum. Self-fluxing solders should become popular in the future, when they are better known.

Soldering commonly requires much less heat than welding or brazing. The solders have melting points one-half to one-fourth as high, and the joints do not need to be annealed or cooled slowly. Hence a mouth blowpipe with a candle flame (Fig. 126) or a foot pump with a gas flame will give all the heat needed. In soldering large joints, where the heat is conducted away rapidly by the body of the metal, a gasoline or kerosene torch is used for preheating, and the solder is melted in a tinner's soldering furnace.

For soldering jewelry and filigree an ordinary blowpipe is used. No special precaution need be taken with the flame, except to keep it hot enough to consume all of its carbon.

I will not try to describe any special soldering process. There are too many metals that can be soldered, and too many ways to solder them, and too many special solders for a given joint. In general, the process of soldering includes: the mechanical cleaning of the surfaces of the metals to be soldered; the heating to a point where the solder will unite with the clean surfaces; the fluxing of the surfaces, before or after heating, so that the metal surfaces will be really clean; the application of the solder with the bit; and the finishing of the joint.

In cleaning the metals, remove the rust and grease with a file, scraper, and a rag or alkali solution. If the flux is a liquid, it is best to first heat the metal a little and then paint on the liquid,

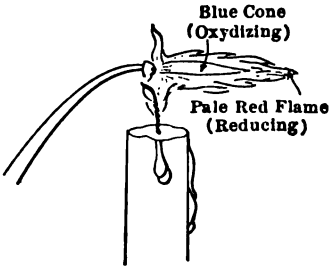

FIG. 127.—How to hold the blowpipe in a candle flame.

which will eat away the oxid film, and will keep the clean surface covered until the solder is applied. If the flux is borax or resin in solution, first apply cold.

The solder is then melted on to the hot clean metal with a torch, or by pressing the hot bit against the solder stick and running it on to the metal. The bit is used to manipulate the solder over the surfaces and to give it the proper shape as it cools.

Among the precautions necessary are to be sure the metals are clean wherever the solder is intended to bind. This can only be done by careful fluxing. Then the metals must be hot enough, but not too hot. If too hot, they will be liable to oxidize, in spite of the flux, should the flux be prepared for a low temperature only. Also, if the metals are too hot, they will make the solder highly liquid. The bit must not be heated too strongly or the tinning

will be driven off and the bit will then be no more capable of guiding and shaping the melted solder than would a stick of wood.

Many soldering runs, such as are found in the manufacture of fruit cans, are now done by automatic machinery; the cleaning, fluxing, and soldering being done in an endless chain, and the machine turning out the finished soldered job in a tenth the time it would take by hand, and making a neater, evener job. The soldering is done by dipping the fluxed metal in a bath of molten solder.

The following solders are used for lead, zinc, copper, brass, iron; and with the addition of cadmium or bismuth, for tin and britannia.

TABLE 33.—MELTING POINTS OF LEAD-TIN SOLDERS[1]

Name	Lead	Tin	Melting point deg. Cent.
Tin	1	1	228
Soft solder	1	2	171
Medium	1	1	188
Hard solder	2	1	227
Lead	1	.....	320

For soldering gold, Gee[2] gives a table of solders with melting points of 983 deg. to 1020 deg. Cent. composed of about 1 part copper to 2 to 5 parts silver, and a small addition of zinc. In making up gold solders, it is quite as important to know what metals should *not* be used. Because gold is very easily ruined by certain metals, lead, tin, arsenic, and antimony should not be used in solders. Antimony is especially injurious, and bismuth in very small proportion will rob gold of its properties.

For silver the hardest solder is 4 parts silver to 1 part copper. A softer solder is 4 silver, 1 copper, and 1 zinc. About 5 per cent. tin makes a quick-running solder. Arsenic in varying amount is also added to soften the solder.

For platinum the solder was commonly gold of ordinary purity, melted on with a strong blowpipe. Since the introduction of the oxy-hydrogen flame, platinum is seldom soldered and almost all joints are welds.

[1] *Brass World*, Nov., 1905.

[2] "The Goldsmith's Handbook," Geo. E. Gee, 1903.

Aluminum has been much experimented on recently (see page 19). There are a number of aluminum solders on the market. One of the best known, Richard's alloy, is composed of 22 tin, 11 zinc, 1 aluminum, 1 phosphor-tin. This is a self-fluxing alloy, due to the action of phosphorus on the aluminum oxid. Aluminum solders are pronounced in general to be unsatisfactory, because aluminum is electropositive to all other metals, and electrolytic action of a destructive nature is apt to set in some time after the joint is made, especially if the joint is exposed to water. Tin is harmful to aluminum and should not be used in its solders. It is claimed that tin will permeate into the aluminum in time and make it rotten and brittle.

THE BLAUGAS PROCESS

Blaugas is the latest addition to the gases used for hot-flame welding and cutting. The production of this gas and its adaptation to welding is the result of a number of years' experimenting by Hermann Blau, a German chemist. The Blaugas System, well established and recognized in Europe, is now in competition in this country with the other welding processes. It is represented by Blaugas Company of America. The advantages claimed for it are:

(1) The safeness and cheapness of the gas. It is not endothermic.

(2) It can be compressed for the market to a very condensed form—liquid.

(3) The high B. T. U. claimed for it—1800 per cubic foot.

(4) The oxy-Blaugas flame is not so hot as the oxy-acetylene, and it is therefore somewhat larger.

Blaugas is the name given to the mixture of gases obtained from the distillation of fuel oil or soft coal at a comparatively low temperature—about 600 deg. Cent. In the ordinary distillation of coal or fuel oil at a temperature of 900 to 950 deg. Cent., the resultant gases are largely permanent hydrocarbon gases produced by the "cracking" of the complex members of the hydrocarbon series. Much pitch is also produced. But at the temperature of 600 deg. Cent. the bulk of the gases are olefines, and are readily liquified under pressure. Little tar or methane and hydrogen are formed.

The manufacture of Blaugas differs from the manufacture of oil gas after the distillate is drawn from the retort. This distillate is subjected to two compressions which liquify those gases which would liquify at comparatively low temperature, and these run off with the water from the cooling spray. The remaining gases are compressed by two more stages to about 100 atmospheres, when the heavier gases are all liquified and absorb most of the permanent gases. The excess hydrogen and methane are used in the compression engine. The tar by-product is sprayed with compressed air into the retort furnace.

Blaugas is shipped in the regulation seamless steel cylinders, which at a pressure of 100 atmospheres contain about 20 pounds of liquid equal to about 400 volumes of gas. Since this liquid is a mixture of gases of varying critical pressures, it would not do to withdraw the product from the cylinder top; the lightest gases would come off first, and the gas would vary continually in value. So a syphon tube extending to the bottom of the cylinder draws out the liquid which expands in the blowpipe or in an expansion cylinder.

Blaugas gives, on analysis, 1042 parts carbon to 204 hydrogen; 1800 B. T. U. per cubic foot are claimed for it; its explosive range is 4 per cent. (4 gas: 96 air, to 8 gas: 92 air); it costs $0.80 per cubic foot. Since it is exothermic it is inert under pressure, and can be safely shipped. The heat of the oxy-Blaugas flame is not given, but seems to be lower than the oxy-acetylene and higher than the oxy-coal gas.

The Blaugas welding apparatus consists of a gas cylinder, an oxygen cylinder, a gas expansion cylinder, rubber tubing, pressure indicating gauges, pressure reducing valves, check valves, torches (high-pressure type), and workman's protective eye shield. Liquid Blaugas is let into the expansion cylinder at a pressure of 50 to 60 pounds and from thence into the torch at 10 to 20 pounds. Oxygen is let directly into the torch at a pressure of 15 to 30 pounds, depending on the thickness of the metal to be cut or welded. The welding torch has five replaceable mouthpieces. The cutting torch has a preheating flame issuing from a circle of nozzles around the cutting, or oxygen, by-pass.

This process both in welding and in cutting seems to be no different in its range from the oxy-acetylene process. The flame is not so hot, and therefore it must be larger. This may be an advantage in some instances and a disadvantage in others.

The Blaugas company recently demonstrated the worth of the system by dismantling the ruins of the burned Equitable Life Assurance Building in New York. This contract involved the cutting of an immense amount of twisted and warped iron girders.

Blaugas also offers a solution for lighting needs in districts where gas and electric current cannot be obtained. Since the gas is inert chemically, non-poisonous, comparatively cheap, and leaves no residue in the pipes or in the burner, it is an ideal gas for lighting.

GLOSSARY OF TERMS

Burnt Metal.—If iron or steel is heated to bright white, it will crystallize when cooled. This will make it brittle, and makes the wrongly called *burnt iron*. To prevent this brittleness the metal must be worked or hammered when cooling. Steel especially is easily *burnt* because its carbon is apt to crystallize with the iron to form brittle alloys, above bright red heat.

Chamfer.—To bevel the edge of a sheet or bar of iron so that it will be the proper shape for welding.

Cold-short.—When a metal is brittle below incandescence. Generally caused by an impurity, as 1 per cent. of phosphorus in iron. Pure zinc is *cold-short* at about 260 deg. Cent.; aluminum above 600 deg. Cent. The latter may be said to be *hot-short*, but not *red-short*.

Critical Temperature.—Used to desginate the temperature at which the metal itself or any important constituent begins to crystallize. The more sharply defined are the critical temperatures, the less weldable is the metal, as high-carbon steel.

Ferrite.—The mineralogical name for pure iron, to distinguish from martensite, cementite, etc., which are terms for the iron-carbon series.

Flux.—Any substance, compound, or mixture used to clean the surface of the substances to be welded or soldered. The flux must be chemically or physically active toward the surface impurities, but not toward the substances to be joined. Sand is a flux for iron, as it forms a fusible silicate with the iron scale, but has no affinity for the iron. Zinc chlorid is a flux for lead, zinc, copper, etc., to be soldered, as it dissolves the surface oxids, leaving a clean surface.

High-carbon Steel.—A general term for a hard, brittle steel. The carbon content is about 0.50 per cent. or more.

Oxidizing Flame.—A flame is commonly caused by the chemical union of oxygen with another substance. If the flame has more oxygen supplied it than is needed for perfect combustion, the free oxygen in excess makes it an oxidizing flame—one that rusts or burns the metal. A flame may be oxidizing in one place and reducing in another.

Red-short.—When a metal becomes brittle at a red heat, it is said to be *red-short.* Generally caused by an impurity, as 1 per cent. of sulphur in iron, or a minute quantity of bismuth in lead or gold.

Reducing Flame.—A flame in which the fuel is in excess of the oxygen necessary for perfect combustion. The tendency of such a flame is to draw some oxygen from the burned parts of the metal. At all events it prevents burning within its radius.

Spelter.—Now used in commerce as the name for pure zinc. Spelter is also the name for half-and-half brass used for brazing. The best way to use this term is not to use it at all.

Swage.—A shaping tool, used in finishing a weld.

Upset.—To enlarge the metal pieces at the place where they are to be welded. The enlargement at the welded joint is called the upset.

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